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THE RELATIONSHIP BETWEEN POWER OUTPUT, OXYGEN CONSUMPTION AND HEART RATE DURING EXERCISE IN THE RAT

by

© PHILIP D. CAMPAGNA III

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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DEDICATION

To my wife Marilyn and late Mother Francis
for their moral support over the years

Abstract

The power output achieved in and metabolic adjustments ($\dot{V}O_2$) to a wide variety of exercise intensities in rats of different aerobic fitness levels was investigated. Thirty male Wistar rats were divided into five groups; sedentary control (SC), exercised-run wheel (E1), exercised (E2), conditioned-run wheel (C1) and conditioned (C2). The animals were trained and/or conditioned on a vertical treadmill for 8 weeks. The SC group was trained for a period of 1 - 2 mins., once a week, while the E1 and E2 groups were exercised twice a week with a progressive increase in duration. The C1 and C2 groups were conditioned four days a week to a maximum of 30 minutes per day. An intermittent test for maximal oxygen consumption was performed at the end of the 7th and 8th week. Expired gases were collected from a nose cone and heart rates recorded. There was no significant difference in maximal oxygen consumption between groups. However, the slope of the linear regression lines for $\dot{V}O_2$ and power output was steeper ($p<0.05$) for the conditioned (C1 and C2 pooled) as compared to the non-conditioned (E1, E2 and SC pooled) groups. This suggests that an adaptation in the conditioned group has occurred. At the lower power outputs, the rats' heart rate increased rapidly to near maximal values. Since $\dot{V}O_2$ continued to rise at power output levels above the levels where heart rate has levelled off, the increased $\dot{V}O_2$ must be achieved by enhanced extraction at the tissue level. Therefore, the different slopes in conjunction with similar maximum $\dot{V}O_2$ values for the different groups suggest that the rat may not be an ideal model for man when studying exercise adaptations in the oxygen transport system.

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INTRODUCTION

For over 100 years, the domesticated rat has been used for scientific studies in Europe. The Norway rat (Rattus norvegicus) was the first animal to be domesticated for the sole purpose of scientific research (Richter, 1968). Adolf Meyer imported the domesticated rat to North America for studies on the brain in 1890 and shortly thereafter, H.H. Donaldson recognized their potential for scientific research and established the famous Wistar colony in Philadelphia (Richter, 1968).

The use of animals such as the laboratory rat in research allows a range of manipulation of both dependent and independent variables, which is often inconvenient or impossible, either for practical or ethical reasons, when studying humans (Plaut, 1975). Experimental variables of interest can be manipulated a great deal with animal populations along with some other factors which otherwise might affect the outcome of the study. Ready access to tissue samples e.g. brain, heart, liver, etc. from the rat are not normally permitted when researching with humans (Plaut, 1975; Lane-Petter, 1976). Furthermore, the undertaking of longitudinal studies as well as replication and the extension of previous work is made possible because of the short-life span (approx. 3 years) and growth period of the rat (Richter, 1968; Plaut, 1975; Roberts and Goldberg, 1976). Of particular advantage the rat's size and economy as well as its high resistance to infection, makes it an ideal model for surgical and physiological studies (Richter, 1968; Plaut, 1975).

The laboratory rat has been used for some time in the medical sciences. It's dietary needs are very similar to those of man, thereby providing discoveries of the nutritive value of vitamins (Matschiner et al., 1967; Bieri et al., 1969). Various strains of laboratory rats have also been bred in order to study cardiovascular diseases (Okamoto, 1964), hypertension (Koletsky, 1973) and obesity (Bray, 1977). The rat has many other medical applications such as clinical investigation of diseases, cancer research, drug research as well as the study of endocrine function and environmental factors.

Until recently, research in exercise physiology has been conducted solely on humans. However, this situation has changed considerably over the past ten years with animal research now being carried out frequently (Oscai and Mole, 1975). A substantial number of studies have examined the acute and chronic effects of conditioning on enzyme activities (Saubert et al.,1973; Hollozy et al., 1975; Hickson, 1976; Jobin, 1976), ligaments and tendons (Tipton et al., 1975; Booth and Gould, 1975), muscular hypertrophy (Goldberg et al., 1975; Baldwin et al., 1977), temperature regulation (Baker and Horvath, 1964; Gollnick and Ianuzzo, 1968; Popovic et al., 1969), hormones (Trenkle, 1974; Gollnick and Ianuzzo, 1975), proteins and nucleic acid concentrations (Wilkinson, 1977), muscle structure (Bowers, 1974; Cosmas and Edington, 1975) and many other variables using the rat as a model.

An underlying assumption when dealing with animal models such as the rat is that it is possible to obtain data on animals

and then extrapolate these findings to humans (Oscai and Mole, 1975). In many cases however, generalizability from animal studies may not always be possible and therefore may just indicate research needed with human subjects (Hardin, 1965; Oscai and Mole, 1975). If exercise physiologists are to extrapolate to man the data which has been obtained on the laboratory rat during exercise, then it is necessary to show similarities between the rat and man. Only in this way can the rat be thereby justified as an adequate model for research in this area.

Although the resting heart rate of the rat is approximately five times that of man, research has shown that bradycardia with endurance conditioning occurs in the rat (Barnard et al., 1976; Tipton, 1965; Lin and Horvath, 1972) as well as in man (Sutton et al., 1967; Frick et al., 1967; Ekblom et al., 1973). The heart rate (Jones et al., 1960) and metabolic adjustment (Shepherd and Gollnick, 1976) of the rat to submaximal steady state exercise is very similar to the pattern observed in man (Mathews and Fox, 1976). Shepherd and Gollnick (1976) have shown a linear increase in oxygen consumption with work intensity (running speed) up to maximum in the rat. This relationship is well established in humans (Astrand and Rodahl, 1970; Mathews and Fox, 1976). Barnard et al. (1974) reported a decrease in maximum heart rate with aging in the rat, which corresponds to the decrease in maximum heart rate seen in man with increasing age (Shepherd, 1968; Robinson et al., 1976).

During an exhaustive run it was shown that heart rates in

the rat were significantly higher than the rates recorded at a submaximal endurance run (Barnard et al., 1974). This is in agreement with Saltin's (1964) data for humans. A graded treadmill test for rats developed by Wranne and Woodson (1973) showed a linear increase in heart rate with an increase in running speed and/or gradient; a well known phenomenon in man (Astrand and Rodahl, 1970; Mathews and Fox, 1976). These results are contrary to the findings of Barnard et al. (1974) who observed heart rate responses to various levels of exercise which are quite different than the response observed in humans. A closer look at their data (Barnard et al., 1974) revealed some interesting findings. In calculating the percentage of maximum heart rate at submaximal levels, they suggested that the relative change in heart rate is from zero beats per minute to the submaximal heart rate and the range of maximum heart rate is from zero to maximum. In doing so, they are implying that the range between zero and resting is a functional portion of the increase and therefore inflate the calculated percentages. Wranne and Woodson (1973) on the other hand used the relative change from resting heart rate to submaximal heart rate and resting heart rate to maximum heart rate as their functional ranges. Therefore, their (Barnard et al., 1974) reported value of 80% maximum heart rate at the lowest power output (13.4 meters/min.) is dramatically reduced to 50% when utilizing the functional range of Wranne and Woodson. Thus, with application of Wranne and Woodson's functional range to the data of Barnard et al. (1974) a linear relationship between heart rate and running speed exists.

Blood lactate levels at maximum work for the rat (Wranne and Woodson, 1973) resemble concentrations that are observed in man at maximal work (Astrand and Rodahl, 1970). According to Popovic et al. (1969) the stroke volume of the rat during exercise does not increase. Similar results are reported in man when muscular work is performed in the supine position (Edington and Edgerton, 1976), the heart is in a similar position in the rat during exercise on the horizontal treadmill.

Although the rat's capacity to dissipate heat appears to be poor, a graded effect on body temperature during exercise to exhaustion (Gollnick and Ianuzzo, 1968) corresponds to observed values reported for humans (Robinson, 1963).

Along with the changes that occur in the cardiovascular system, major biochemical adaptations can occur in skeletal muscle with conditioning. Mammalian skeletal muscles have been classified by a number of different systems during the past fifteen years (Close, 1972). The classification scheme utilized by Peter et al. (1972) seems to be the most functional. They classify muscle fibers as fast-twitch-glycolytic (FG), fast-twitch-oxidative-glycolytic (FOG) and slow-twitch-oxidative (SO) according to contractile speed and metabolic properties. There are a few basic metabolic differences among the skeletal muscles of the rat and human. In man, the SO muscle fiber has the highest oxidative potential, while the FOG has an intermediate oxidative potential lying somewhere between the SO and FG fibers (Holloszy et al., 1975). The SO muscle fiber of the rat on the other hand has intermediate

oxidative potential with the FOG fiber being the most oxidative (Holloszy et al., 1975). It should be pointed out that the fiber composition of human skeletal muscle is heterogeneous in nature. Whereas, in the rat a number of muscles such as the soleus and plantaris are relatively homogeneous in their fiber composition. Although this appears to be a disadvantage in attempting to extrapolate from rat to man, it allows the researcher an opportunity to examine the relative effect of various conditioning protocols on certain fiber type populations (Holloszy and Booth, 1976).

Holloszy (1967; 1973) has shown that major biochemical adaptations occur in skeletal muscle of the rat with endurance conditioning. A finding of similar biochemical adaptations has been confirmed by Morgan et al. (1971) for human subjects. Depletion of glycogen stores has been reported to occur in both rat (Gollnick et al., 1970) and man (Lappage, 1969; Taylor, 1971) during prolonged exercise. Free fatty acid utilization and uptake as well as their release from adipose tissue has also been shown to be influenced by prolonged activity in both rat (Jones and Havel, 1967) and man (Hagenfeldt and Wahren, 1971). Many investigators have reported an increase in skeletal muscle glycogen content for rats (Grollman, 1955; Gollnick et al., 1970) and man (Bergstrom and Hultman, 1966; Lappage, 1969) following regular conditioning programs. An increase in total mitochondrial protein due to increases in the size and number of mitochondria, has been reported in skeletal muscle in both man and rats (Holloszy and Booth, 1976).

From the substantial number of comparisons that have been

presented, it is suggested that the laboratory rat is an excellent experimental model for research in exercise physiology.

Exercise physiologists have employed running and swimming programs most frequently to evoke a conditioning response. The motor-driven treadmill (Critz and Merrick, 1962; Andrews, 1965; Bhatia et al., 1966; Koniski, 1966, Brannon et al., 1968), running wheel (Wells and Heusner, 1971) and exercise drum (Jenner and Byrd, 1974; Shepherd and Gollnick, 1976) are the most common modes for running the laboratory rat. Many laboratories use swimming as a form of exercise with the addition of weights as a means of standardizing the workload (Dawson and Horvath, 1970).

Quantification of the work done by each animal while swimming is unknown and may be influenced by a number of factors (Griffiths, 1960; Baker and Horvath, 1964a; McArdle, 1967; Hardin, 1968). Treadmill running, exercise drums and running wheels provide some control over the speed at which the animals are to train, however, because of the horizontal component the amount of work or power output actually performed is difficult to calculate in physical terms (Hardin, 1965).

Researchers have employed various conditioning protocols over the past ten years and have shown a number of physiological changes. Table 1 represents a number of conditioning protocols that have been reported in the literature. A few authors (Baldwin et al., 1977) have made an attempt to justify the conditioning protocol used, however, the majority give no rationale for the selection of the speed, incline, frequency and duration. Often

TABLE 1 A SELECTION OF CONDITIONING PROGRAMS UTILIZED BY RESEARCHERS

AUTHOR & YEAR	SPEED (m/min)	INCLINE (deg)	FREQUENCY (days/wk)	WORK TIME (mins/day)	DURATION (weeks)	APPARATUS
Bagby, 1972	26.8	?	5	60	11	treadmill
+ Edington, 1973	30	8	5	60	16	treadmill
Taylor, 1974	26.8	?	5	60	12	treadmill
# Borensztajn, 1975	31	8	5	120	12	treadmill
Barnard, 1976	?	?	5	60	12	treadmill
Hickson, 1976b	36	-	5	50	8	run-wheel
Terjung, 1976	26.8	5.7-8.5	5	60	12-18	treadmill
Wachtova, 1976	18-20	?	?	120	7.6	treadmill
* Baldwin, 1977	26.8	14	5	60	8	treadmill
Fitts, 1977	32.2	8.5	5	120	27	treadmill
Pitts, 1977	18	8	7	60	15	treadmill

? not reported

* justification of conditioning program

12 intervals of running at 42m/min., each lasting 30 sec., spaced 10 min. apart

+ 2 min. rest periods every 10 min.

important information is not reported, thereby making comparisons between studies extremely difficult (see Table 1).

If the primary objective of a conditioning program is to achieve optimal improvements in a selected variable then application of the progressive overload principle is essential (Mathews and Fox, 1976). With endurance conditioning the intensity of the program rather than the duration has been reported to elicit the greatest improvements (Shepherd, 1969; Wenger and Macnab, 1975). Astrand and Rodahl (1977) have stated that "an adaptation takes place to a given load; in order to achieve further improvements, the training intensity has to be increased."

A common procedure is to progressively increase the speed of the treadmill and duration of the run during the first few weeks and then to maintain the animals at a selected speed and duration throughout the remainder of the experiment. Whether the procedures employed by most researchers (see Table 1) progressively overload the rat throughout the entire duration of the study is questionable. If the intent is to compare the adaptation of conditioning and/or exercise between the rats of various studies or to extrapolate to man, then the relative intensity of the conditioning program should be known. The determination of the precise power output the rat is performing on the horizontal treadmill is seriously confounded by the horizontal component of running and/or gait changes.

A vertical treadmill has been designed which allows the power output performed by the rat to be measured (Russell et al.,

1978). Along with the measurement of oxygen consumption (considered the best measure of aerobic metabolic rate) researchers will be able to determine the relative intensity of their conditioning programs.

Thus, if mechanical and metabolic work as well as the heart rate responses to different loads can be determined, it will enhance the capability to quantify the conditioning stimulus. This will in turn improve the generalizability to humans during exercise.

The purpose of the study is:

To determine the relationship between the power outputs achieved in and heart rate and metabolic adjustments ($\dot{V}O_2$) to a wide variety of conditioning intensities in rats of different aerobic fitness levels.

Terminology

Maximal oxygen consumption - the maximal rate at which oxygen can be consumed/minute.

Power output - performance of work expressed per unit of time.

Training - activity designed to teach a particular skill.

Exercise - any physical activity not intended to improve skill, strength or endurance, but to maintain these.

Conditioning - activity designed to improve the physical performance such as strength or endurance, as opposed to skill.

METHODOLOGY

ANIMAL SELECTION AND CARE

Thirty male Wistar rats (WOF (WI) Specific pathogen free CFN) approximately five to seven weeks of age were obtained through the Director of the Health Sciences Animal Center at the University of Alberta from the Woodlyn Farms, Guelph, Ontario. Upon arrival, the animals were randomly assigned to one of five groups; a control group (SC), two exercised groups (E1 and E2) and two conditioned groups (C1 and C2). The control group (SC) was essentially given no exercise, although they were exposed to the treadmill once a week. The exercised group E1 was exercised on the treadmill twice a week and had voluntary access to a running wheel (see Fig. 1). Whereas,

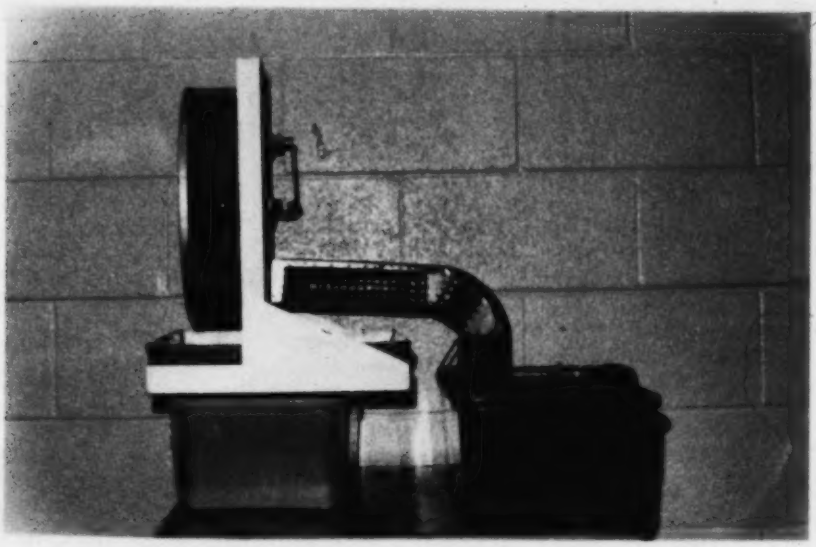


FIGURE 1 VOLUNTARY RUNNING WHEEL

TABLE 2 DESCRIPTION OF EXPERIMENTAL GROUPS AND NUMBER OF ANIMALS ASSIGNED TO EACH CONDITION

ANIMAL GROUP	NUMBER OF ANIMALS (N)
SC[1] - Sedentary control group (no exercise)	10
E1 - Exercised group (exercised on treadmill twice a week, access to running wheel)	5
E2 - Exercised group (exercised twice a week on a treadmill)	5
C1 - Conditioned group (conditioned 4 d/wk. on a treadmill, access to running wheel)	5
C2 - Conditioned group (conditioned 4 d/wk. on a treadmill)	5

[1]Although this group is designated as receiving no exercise, they were exposed to the treadmill once a week.

exercised group E2 was exercised only twice a week on the treadmill. Both conditioned groups C1 and C2 were conditioned on the treadmill four days a week, however the C1 group had voluntary access to a running wheel (see Table 2). The animals were housed in standard 9" x 18" x 6" cages. Animals in groups E1 and C1 (Table 2) were exposed to the running wheels on alternate days because of a limited number of running wheels.

Purina rat chow containing 23% crude protein and water was provided ad libitum. All animals were given a week to adapt to the new environment which included a reversal of the day-night cycle (light 6 pm. to 6 am.). Weighing of all animals in groups SC, E2

and C2 was carried out every 3 to 5 days (see Appendix B-1). Animals in groups E1 and C1 were weighed every day (see Appendix B-1). Each morning, the cages were rotated on the cage rack, soiled papers in the running wheels were changed and food and water replenished.

DESCRIPTION OF TREADMILL

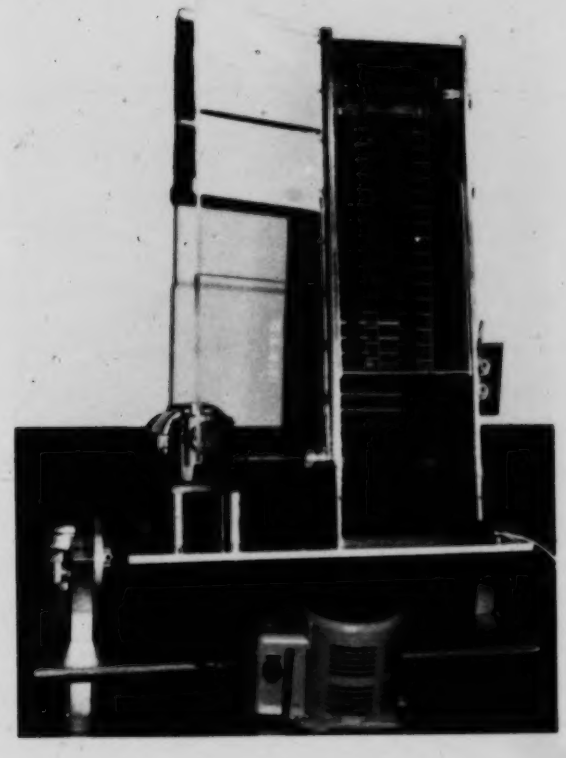
The animals were trained and conditioned on a vertical treadmill (rotating ladder) consisting of 3/8" roller chains, 1.11 meters in length, connected by 3/10" rods with a 3/4" pitch (see Fig. 2 and Fig. 3). The ergometer is powered by a General Electric D.C. variable speed motor which allows the experimeter a constant speed range of 5.7 to 17.4 meters per minute. Small variations in vertical elevation are possible with a range of 69° to 90° (see Appendix C). Motivation to run was provided by a compressed air jet, which was hand-held at the bottom of the treadmill.

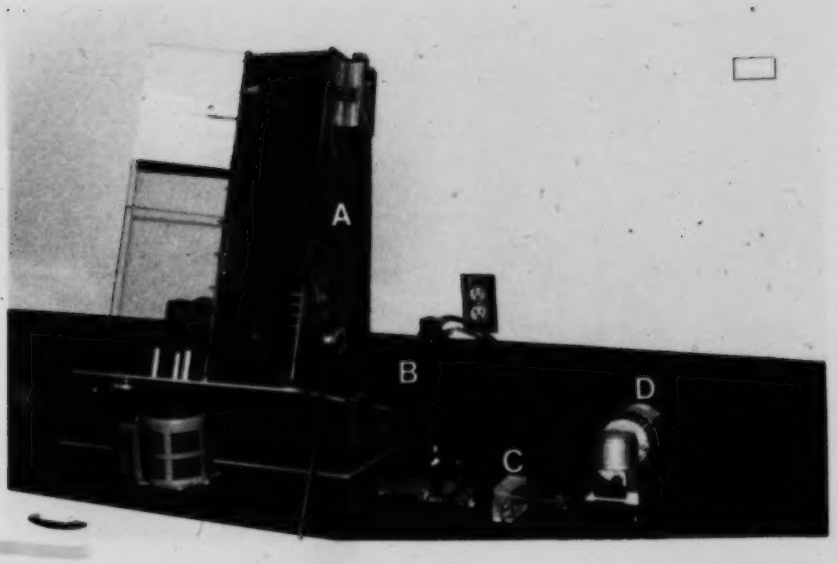
TRAINING PROTOCOL

At the end of the adaptation week, all animals were given seven days of orientation to climbing on the vertical treadmill. Following this brief orientation, the maximum heart rate was determined for each animal by progressively increasing the speed until no further increase in heart rate occurred. For the remainder of the study, the sedentary control group (SC) was trained for a period of 1-2 minutes once a week (Sat.), while the exercise groups E1 and E2 were exercised twice a week (Wed. and Sat.) with a progressive increase in duration (see Appendix D-1). The conditioned groups C1 and C2 were conditioned four days a week (Mon., Tues., Thurs. and

Figure 2 Front view of vertical treadmill

Figure 3 Vertical treadmill and equipment for the measurement of expired gases (A, vertical treadmill; B, flow meter; C, mixing chamber; D, vacuum pump)

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Each conditioning day consisted of two sessions of progressive duration up to a maximum of fifteen minutes for most animals (see Appendix D-2). The morning sessions were held between 0700 and 1000 hours and the afternoon sessions between 1400 to 1700 hours.

In an attempt to progressively overload the animals in groups C1, C2, E1 and E2. a criterion heart rate from 580 to 610 beats per minute was chosen for each animal. As the maximum heart rate decreased with aging, the criterion heart rate was reduced to a range of 570 to 590 beats per minute. The speed of the treadmill was therefore adjusted to maintain the animal at the criterion heart rate (see Appendix H) so that the same relative intensity was maintained throughtout.

Since precise measurements of power output will enhance the capability to quantify the training stimulus, a pilot study was carried out in an attempt to determine the steepest incline, animals could manage and still have a sufficient duration of exercise. From 69° to 76° there was little difference in running times. However, longer running times were found to occur at 76° than at steeper grades. The small angular difference allows the rat to exercise on the treadmill without having his center of gravity outside his hind feet. Therefore, the overhead work of maintaining this position is minimized. The vertical distance travelled is determined by finding the sine of angle theta (θ) times the distance travelled (Mathews and Fox, 1976). The sine of 76° is 0.97, however

increasing the incline to 90° only increases the sine θ to 1.00. Therefore from a physical point of view, 76° will allow precise measurements of vertical distance travelled as well as provide a sufficient duration of exercise.

EXPERIMENTAL DESIGN

In the present study, five groups of experimental animals were selected (Table 2). The number of training and conditioning days, access to running wheels (for some animals) and a variety of conditioning intensities were employed in an attempt to obtain a wide range of maximal oxygen consumption values.

An intermittent test for maximal oxygen consumption was performed at the end of the seventh week. The duration of the study depended upon the animals reaching asymptote of maximal oxygen consumption, inspite of additional conditioning. A levelling off criterion of 5% or less over a one week period was established for termination of the study. At the end of the eighth week, all but two animals showed a levelling off of maximal oxygen consumption. The remaining 2 animals showed a levelling off at the end of the nineth week.

At the end of the nineth week, three animals were trained to run on a horizontal treadmill (Collins) consisting of a wide endless belt on rollers divided into 5 compartments. Motivation to run was provided by a compressed air jet, which was hand-held at the back of the compartment. After three consecutive training days, a sub-maximal oxygen consumption test was performed. The animals ran at a variety of speeds and inclinations for a duration of three minutes

each (Table 4).

DETERMINATION OF HEART RATE

During the week of adaptation, two electrodes were placed on each animal for determination of heart rates. The rats were anesthetized lightly with halothane using a Fluotec 3 vaporizer. Two stainless steel 3-0 monofilament sutures were placed bilaterally on the back of the animal approximately one inch from the dorsal midline and just above the scapula (Eisentein and Woskow, 1958).

When heart rates were recorded, two Mueller #34c alligator clips soldered to a length of Belden #8429-10 twisted cable were clipped to the sutures on the animal's back. EKG paste was applied to the ends of the alligator clips to provide a better conductive medium between the sutures and clips. The leads were then connected to a Sanborn 350-3200A ECG Preamplifier. For the purposes of the conditioning sessions, a storage oscilloscope was connected to the output of the ECG Preamplifier (see Fig. 4).

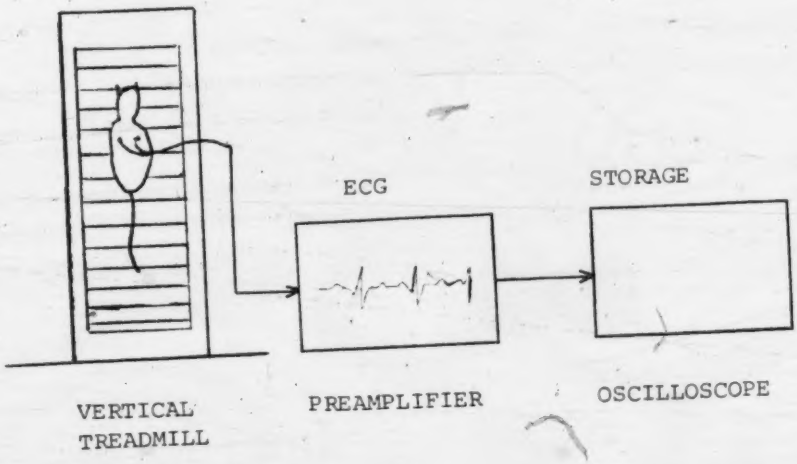

FIGURE 4 A SCHEMATIC REPRESENTATION OF THE APPARATUS FOR DETERMINATION OF HEART RATE

Heart rates were recorded during basal conditions, resting in the cage, pre-exercise and during exercise. Basal heart rates were recorded during the light portion of the daily cycle. If at all possible, care was taken to not awaken the animal during the measurement of basal heart rates.

DETERMINATION OF OXYGEN CONSUMPTION

For the collection of the expired gases, a nose cone (see Fig. 5 and 6) was developed (open system). Its operation depended upon a negative pressure with the air drawn through by a vacuum pump. Air flow was measured by a Matheson 0.200 - 20 liter flowmeter (see Fig. 3). The rate of air flow was set at 5.5 liters per minute. The air samples were immediately analyzed by a Beckman metabolic cart. A 500 ml. aliquot of air was sampled from the mixing chamber (see Fig. 3) and analyzed for $\%O_2$ and $\%CO_2$ by means of an OM-11 oxygen analyzer and a LB-2 carbon dioxide analyzer. Reference gases of a known concentration (Consumer' Welding Supplies Ltd.) were used for calibration of the gas analyzers. The total response time of the system was eight seconds. Calculation of oxygen consumption was corrected for STPD.

Maximal oxygen consumption was determined by a discontinuous treadmill test. The animal climbed for four minutes, followed by a rest period of approximately 10-15 minutes. The treadmill speed was then increased and the procedure repeated. Expired gases were measured throughout the test until an asymptote occurred or a decrease in oxygen consumption was produced with increased power output.

Figure 5 Collection of pre-exercise oxygen consumptions from a rat on the vertical treadmill

Figure 6 Mask utilized for collection of expired gases

DETERMINATION OF POWER OUTPUT

The power output performed by the animal is reported in SI units (watts). The following equation was applied to calculate the power output (Russell et al., 1978):

$$P = W \times V \times 9.80 \times 10^{-3} \times \text{Sin } \theta$$

where: W is the animals weight in grams.

V is the ladder velocity in meters per second.

θ is the angle between the ladder surface and horizontal.

STATISTICAL ANALYSIS

A one-way analysis of variance (Winer, 1977) was carried out on the data to compare groups. The Newman-Keuls test was used as a post hoc procedure to locate significant differences between group data which was pooled into either conditioned or unconditioned groups. Group regression lines were calculated using all data points from each animal (up to VO_2 max). A test for homogenity of regression was used to test the slopes of the regression lines for the conditioned (C1 and C2 pooled) and unconditioned (E1, E2 and SC pooled) groups. An alternative method for calculating the group regression lines was used (post hoc), where the slopes of the individual regression lines (Appendix E) for each group were averaged (see Addendum). Significant differences were accepted at the alpha level p is less than 0.05, where p is the probability that no difference exists.

Results

The results are summarized in tabular and graphical form representing the mean values and standard error of the mean (SEM) for each group. Raw data of the dependent variables for all experimental animals can be found in Appendix B. Individual regression lines for oxygen consumption (l/min) and power output for each animal is located in Appendix E. Tables of statistical analysis and post hoc procedures are located in Appendix F.

Body weights increased with growth throughout the experiment with no difference between groups at the beginning of the conditioning program (Fig. 7). The sedentary control (SC) and exercised (E2) group showed the highest body weight at the end of the experiment and were not different from each other ($p>0.05$). In descending order the exercised-run wheel (E1), conditioned (C2) and conditioned-run wheel (C2) were different from the former two groups and from each other ($p<0.05$) after 58 days (Fig. 7).

Maximal oxygen consumption/unit body weight is illustrated in Fig. 8. The exercised group (E2) has a significantly lower maximal oxygen consumption (ml/kg/min) than the sedentary control (SC) and the conditioned groups (C1 and C2). There was no difference ($p>0.05$) among groups in maximal oxygen consumption when expressed in l/min.

The linear regression lines for the oxygen consumption (l/min) and power output for each experimental group is shown in Fig. 9. The slope for the conditioned groups (C1 and C2 pooled) was steeper ($p<0.05$) than the slope for the non-conditioned group (SC, E1 and E2 pooled).

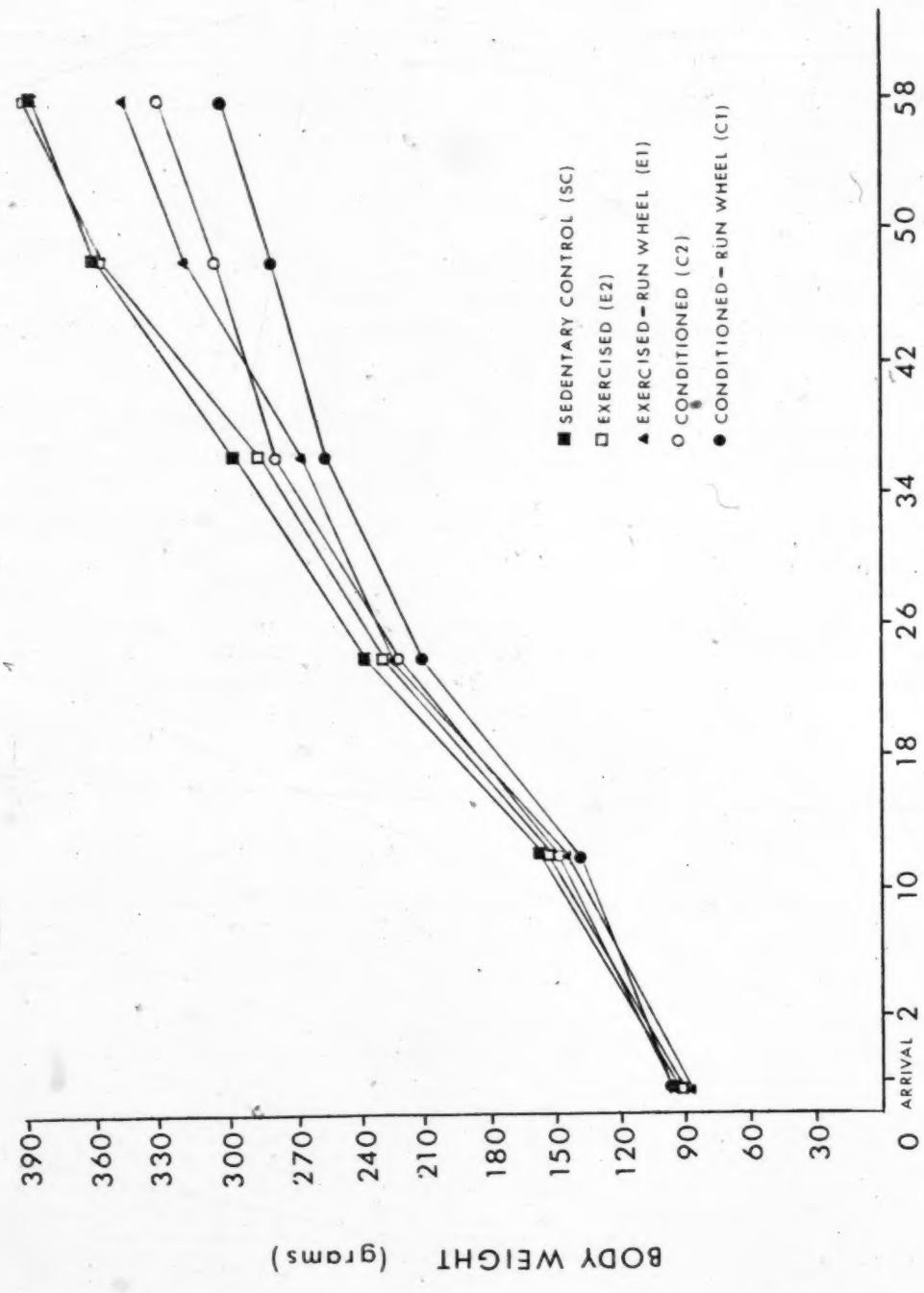

Figure 7 Progression of body weight for the different experimental groups

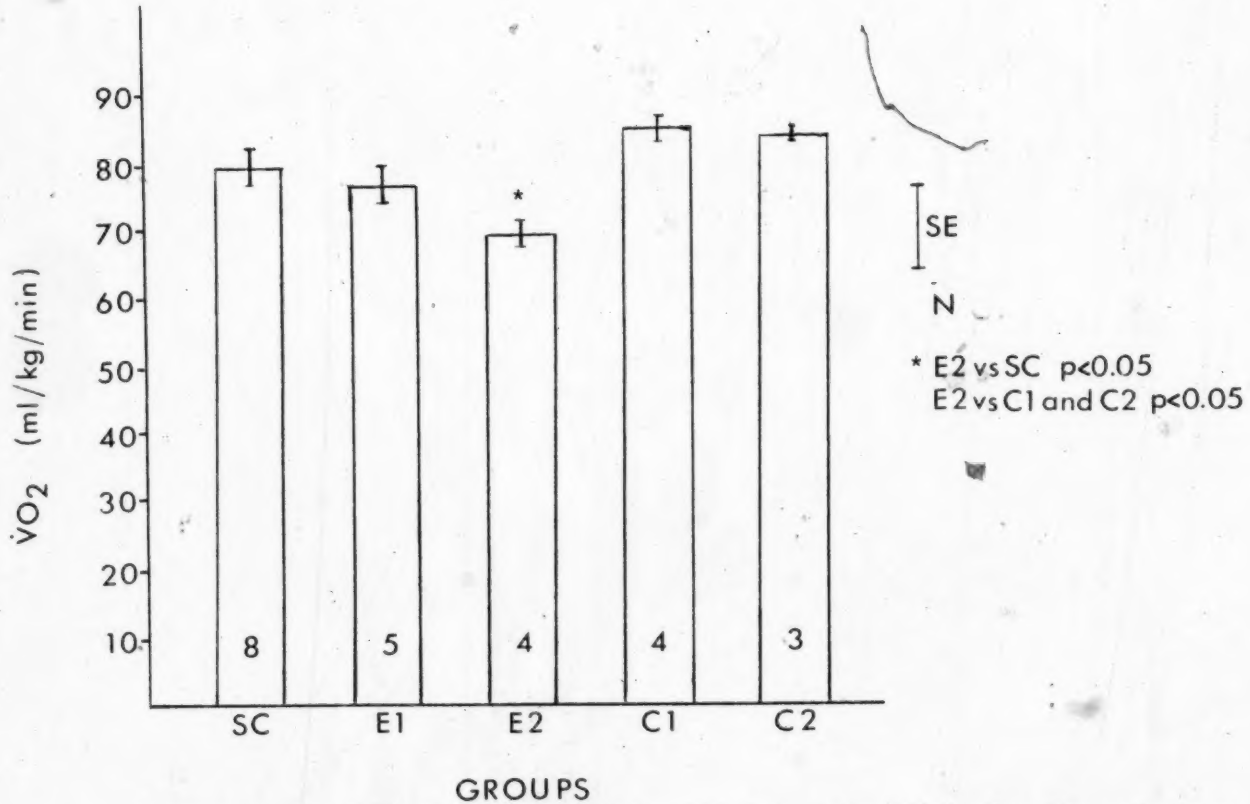

Figure 8 Maximal oxygen consumption per unit body weight for the sedentary control (SC), exercised-run wheel (E1), exercised (E2), conditioned, run wheel (C1) and conditioned (C2) groups at the end of the experiment

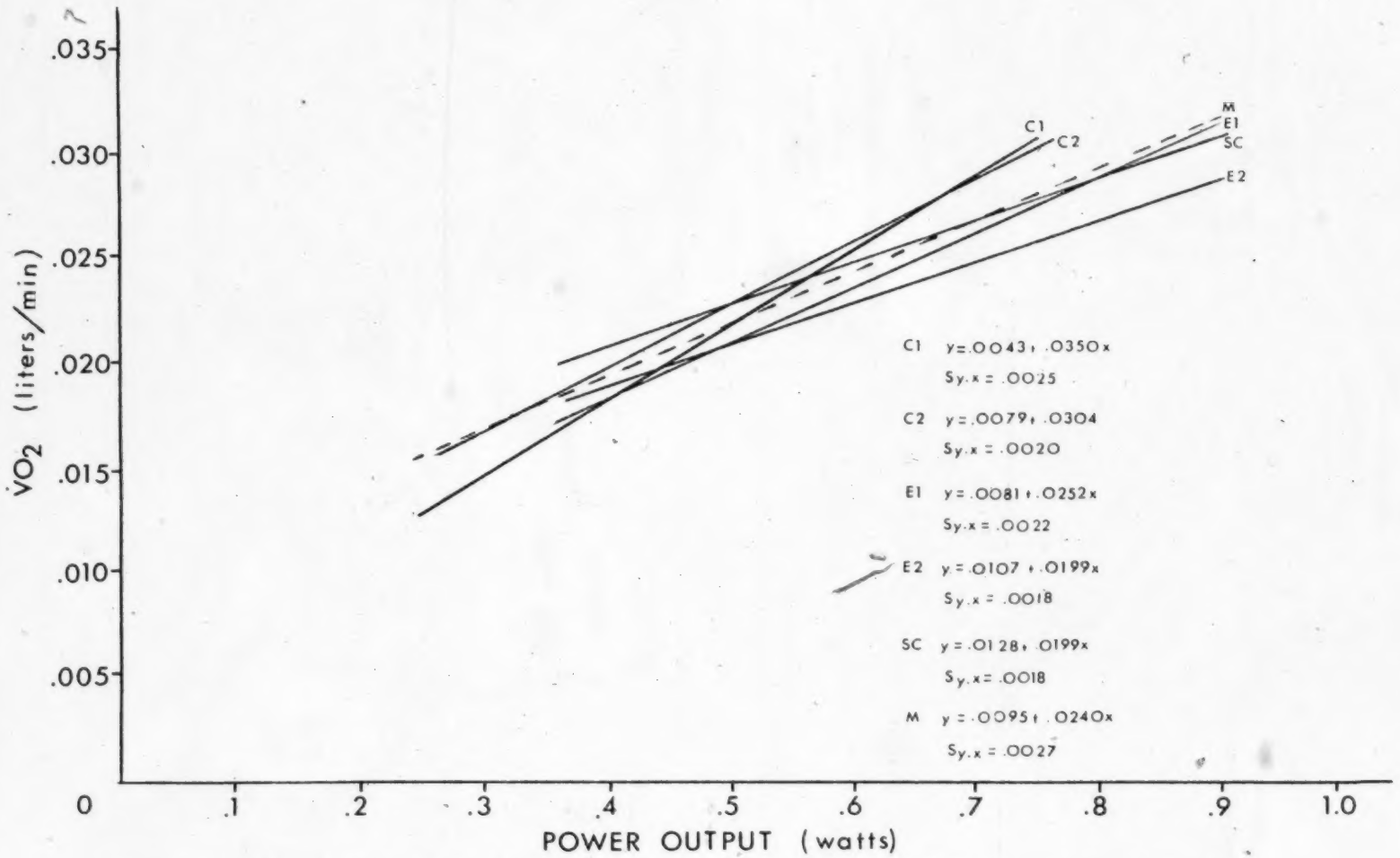

Figure 9 Linear regression lines of oxygen consumption (l/min) and power ouput for the conditioned-run wheel (C1), conditioned (C2), exercised-run wheel (E1),exercised (E2), sedentary control (SC) groups and overall regression (M) line

Table 3 Heart rates at different levels of activity obtained from the rats during the 2nd and 8th week of the experiment

	Basal (asleep)	Resting in cage	Pre-exercise	Maximum Exercise	Paroxysmal Tachycardia
2nd week	407(6) ±10	447(6) ±21	504(25) ±4	647(25) ±3	844(1)
8th week	300(5) ±8	354(4) ±12	403(20) ±5	597(20) ±3	-

$\bar{x}$ ± SE (N)

There was no significant difference in pre-exercise oxygen consumption (ml/kg/min) for the experimental groups (Appendix B).

Heart rate data obtained from rats during the 2nd and 8th week of the experiment is shown in Table 3. Maximum heart rate decreased ($p<0.01$) from 647 ± 3 beats/min. during the 2nd week to 596 ± 3 beats/min. in the 8th week of the experiment. There was no significant difference in maximal heart rate between the experimental groups at either the 2nd or 8th week. Pre-exercise heart rates decreased ($p<0.01$) from 504 ± 4 beats/min. during the 2nd week to 403 ± 5 beats/min. in the 8th week. There was no significant difference in the pre-exercise heart rate between the experimental groups in either the 2nd or 8th week of the experiment.

The resting heart rates recorded in the cages after one-half hour rest decreased ($p<0.01$) from 447 ± 21 beats/min. in the 2nd week to 354 ± 12 beats/min. in the 8th week. Basal heart rates while the animals were asleep also showed a decrease ($p<0.01$) from 407 ± 10 beats/min. in the 2nd week to 300 ± 8 beats /min. in the 8th

week of the experiment.

Figure 10 shows the relationship between heart rate and power output for the different experimental groups. At the lower power outputs, the rats' heart rate increased rapidly to near maximum values and then plateaued.

Horizontal Treadmill Exercise

Submaximal oxygen consumption and heart rate values obtained while selected animals were running on the horizontal treadmill are shown in Table 4. Oxygen consumption and heart rate increased progressively when speed was held constant and grade elevated or vice versa. The power output was calculated from the vertical component only and does not include the horizontal component of running.

Table 4 Submaximal measurements of three rats at varying running speeds and inclinations on the horizontal treadmill

Animal	Weight (grams)	Speed (m/min)	Grade (degrees)	Power Output (watts)	Heart Rate (b/min)	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)
BL3	246	26.8	4	0.075	529	0.0131	53.2
PRR	349	24.8	4	0.106	546	0.0197	56.5
GR1	343	26.8	4	0.105	563	0.0156	45.5
BL3	246	26.8	10	0.187	546	0.0169	68.7
PRR	349	26.8	10	0.265	581	0.0201	57.7
GR1	343	26.8	10	0.260	584	0.0178	52.0
BL3	246	26.8	16	0.297	554	0.0192	78.1
PRR	349	26.8	16	0.421	590	0.0206	59.1
GR1	343	26.8	16	0.413	595	0.0187	54.6
BL3	266	30.0	4	0.090	546	0.0101	38.5
PRR	357	30.0	4	0.122	552	0.0204	57.2
BL3	266	30.0	10	0.224	581	0.0181	68.8
PRR	357	30.0	10	0.304	577	0.0250	70.0
BL3	266	30.0	16	0.355	590	0.0204	77.8
PRR	357	30.0	16	0.482	590	0.0278	77.7
BL3	263	35.0	4	0.104	563	0.0133	51.1
BL3	263	35.0	10	0.258	581	0.0175	67.1

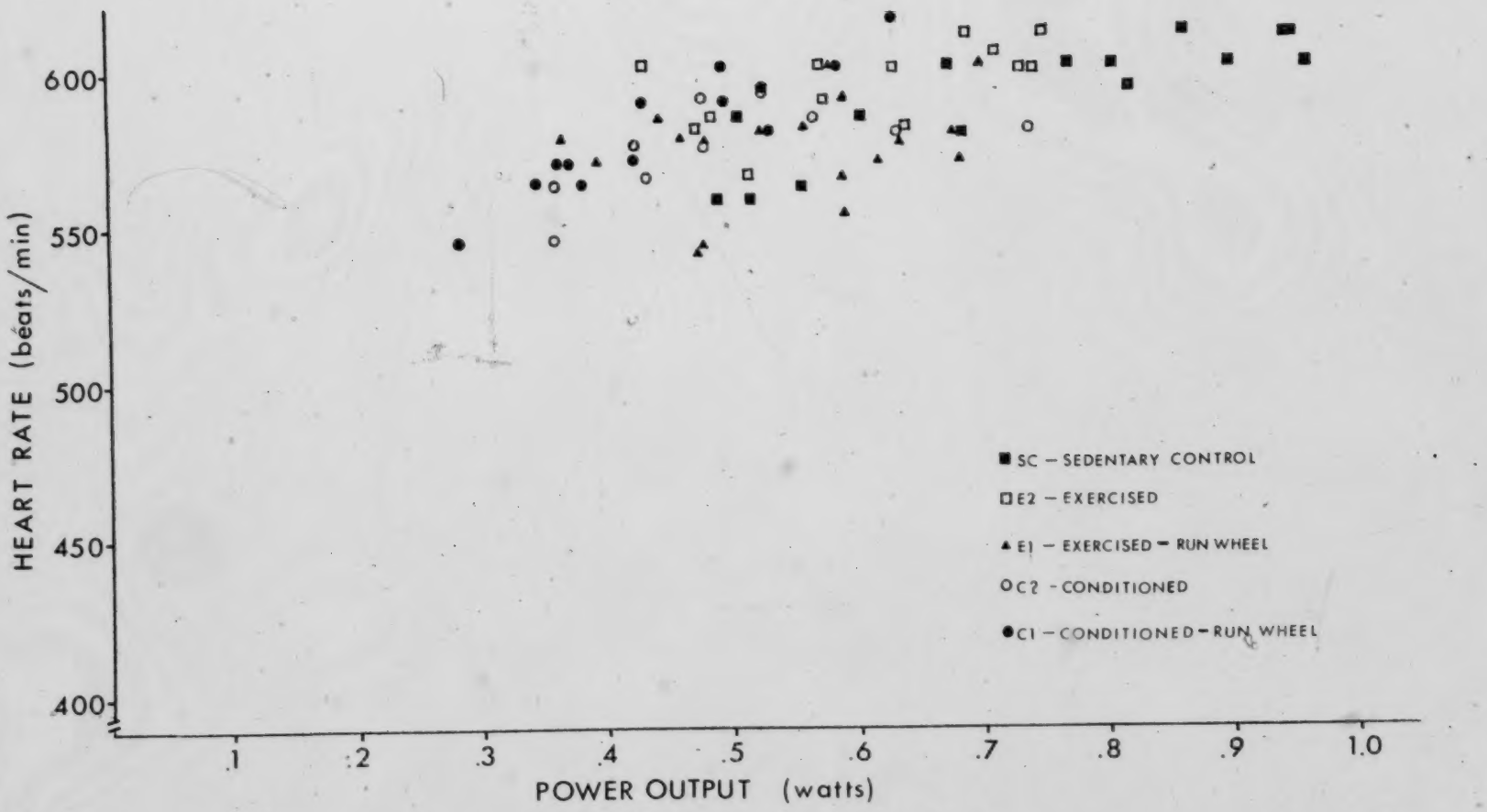

Figure 10 The relationship between heart rate and power output for the different experimental groups

Discussion

Body weight progressively increased throughout the duration of the study in all experimental groups (Fig. 7). This observation has been well documented in a variety of conditioning and exercise programs such as isometric conditioning (Zika et al., 1975; Exner et al., 1973a and b), sprint conditioning (Staudte et al., 1973; Houston and Green, 1975; Hickson et al., 1976a), endurance conditioning (Baldwin et al., 1975; Huston et al., 1975; Muller, 1975). Houston and Green (1975) suggested that an appetite-suppressing effect occurs when rats are subjected to a vigorous conditioning program. This effect may combine with an increased energy expenditure thereby resulting in a smaller increase in the body weights of the exercised and/or conditioned groups.

At the conclusion of the present study, the group that exercised once a week (E2) did not differ in body weight from the sedentary control group. However, the other experimental groups had significantly lower body weights than the E2 and SC groups and were also significantly different from each other (Fig. 7). The experimental group exposed to the greatest amount of total work (C2 : conditioned-run wheel) displayed the least weight gain followed by the conditioned (C1) and exercised-run wheel (E1) groups respectively. It appears that body weight changes are not only dependent upon the age and sex of the animal but also upon the intensity, duration and total work of the exercise and/or conditioning program.

The most popularly used procedure to evaluate the intensity

or quantity of metabolic overload in an exercise bout has been the measurement of oxygen consumption (Scheur and Tipton, 1977). It reflects the efficiency of uptake, transport and utilization of oxygen by the cardiorespiratory and muscular systems. The maximal oxygen consumption values observed in the present study ranged from 64.4 to 90.7 ml/kg/min. (Fig. 8). The experimental group that exercised (E2) twice a week had a significantly lower maximal oxygen consumption than the sedentary control (SC) and conditioned groups (C1 and C2). There seems to be no apparent reason for the lower values obtained from the E2 group as compared to the sedentary controls. There was no significant difference in maximal oxygen consumption between the other experimental groups in spite of substantially different amounts of chronic exercise. The values reported in this study are slightly lower than those previously reported in the literature for rats running on a treadmill or running wheel. Wilson et al. (1978) reported maximal oxygen consumption values of 91 ± 2 and 87 ± 2 ml/kg/min. for unconditioned male and female rats respectively. Shepherd and Gollnick (1976) reported a maximum value of 95 ± 1.4 ml/kg/min. for male rats conditioned five days a week for a period of six weeks. A number of possible reasons exist for the higher values reported in the literature. For example, Wistar rats were used in the present study, whereas Shepherd and Gollnick (1976) selected rats from the Sprague-Dawley strain. Wilson et al. (1978) chose Okomato-Aoki as well as Sprague-Dawley rats for their study. The type of ergometer utilized to obtain maximal values was different in each study. Wilson et al. (1978) employed a horizontal treadmill

while Shepherd and Gollnick (1976) used a motor-driven running wheel. In the present study, a vertical treadmill was used which required a climbing motion rather than a running motion. Both Shepherd and Gollnick (1976) and Wilson et al. (1978) failed to report their values corrected to S.T.P.D. (Standard, Temperature, Pressure, Dry, e.g. 760 mmHg., 0° C.). This was likely an oversight. However, if the reported values were not corrected to S.T.P.D., the differences in maximal oxygen consumption between this study and the reported ones would not exist. The maximal oxygen consumption values reported for swimming rats range from 55 to 80 ml/kg/min. (Baker and Horvath, 1964b; Kratzing and Mark. 1967; McArdle, 1967; Dawson and Horvath, 1970). These reported values are lower than the observed values in the present study. It is difficult to compare swimming to running since the physical quantification of the power output while swimming is very difficult. McArdle (1967) has suggested that the addition of weight to the swimming rat does not increase the oxygen consumption but actually reduces the ability of the animal to exchange gases at the surface. The lower values of maximal oxygen consumption obtained while swimming would suggest that swimming lends itself to submaximal exercise programs but is less suitable to overloads of near maximal intensity.

Since there was essentially no difference in maximal oxygen consumption between experimental groups, one could conclude that the conditioning program produced no change in the aerobic capacity of the rats. However, when the slopes of the regression lines for the conditioned (C1 and C2 pooled) and non-conditioned (SC, E1 and E2 pooled) groups are compared, they differ significantly

(Fig. 9). This suggests that an adaptation in the conditioned group has occurred. A possible explanation is that at the higher power outputs the conditioned rats were able to meet the increased demands through increased aerobic catabolism whereas, the non-conditioned animals derived a greater percentage of the required energy to perform the work from anaerobic sources. This could imply that chronic conditioning, as performed in this study, elicits an increased emphasis on aerobic metabolism at higher power outputs rather than an elevated maximal oxygen consumption. In man oxygen consumption at submaximal power outputs are very similar but the conditioned athlete is able to extend his oxygen consumption. The different slopes (also see Addendum) in conjunction with similar maximal oxygen consumption values for the different groups suggests that the rat may not be an ideal model for man when studying exercise adaptations in the oxygen transport system.

Pre-exercise oxygen consumptions were higher (34 ± 2 ml/kg/min.) than most values reported in the literature (Kratzing and Mark, 1967; Popovic et al., 1969; Shepherd and Gollnick, 1976). Since the rats were accustomed to wearing the mask only when placed on the treadmill, it is suggested that they were anticipating the start of exercise. This is consistent with the elevated resting oxygen consumptions reported by Shepherd and Gollnick (1976) and also with the anticipatory rise in colonic temperature of rats prior to exercise reported by Gollnick and Ianuzzo (1968). Also the mask itself may precipitate elevated metabolic rates in contrast to the chambers used traditionally.

The individual regression line for oxygen consumption

and power output indicates that a linear relationship exists (Appendix E). This is consistent with the findings in man (Mathews and Fox, 1976). The adjustment to submaximal steady state exercise in the rat also follows a pattern that is often documented in human research (Astrand and Rodahl, 1977). There was a 3 to 4 minute period before oxygen consumption plateaued and in many cases then showed a drop which is frequently evident in man. Hence, although the response to increasing power outputs is quite different in the rat model, the lag time associated with the slow accomodation in the cardiovascular system to a single power output is comparable to man.

The maximal heart rates observed during the 2nd and 8th experimental week (Table 3) are considerably higher than those previously reported by other investigators (Barnard et al., 1974; Wranne and Woodson, 1973). Since the rats in the present study were younger than those in Barnard et al. (1974) and Wranne and Woodson's (1973) studies, it is possible that the elevation was due to the use of younger animals. Another explanation may be the different spacial orientations of the heart. When the rat is running on the horizontal as in the two former studies, the relationship between the heart and the body may be likened to the supine position in man, where stroke volume is at maximum due to maximal venous return (Edington and Edgerton, 1977) and hence heart rates may not be elevated to the same extent to meet the same cardiac outputs. On the vertical treadmill, the heart must work against the forces of gravity to move blood from the lower extremities and to the upper extremities. This may drop stroke volume and hence heart rates

must be elevated to meet the required cardiac output. In the present study, a decrease in maximal heart rate with aging was observed which is consistent with the findings of Barnard et al (1974). This observation is similar to that reported in man (Shepherd, 1968; Robinson, 1978).

Pre-exercise heart rates (Table 3) are similar to those reported by Barnard et al. (1974) and Wranne and Woodson (1973). During the second experimental week, the pre-exercise heart rates were significantly higher than during the eighth week, suggesting that at the younger age the animals were more excitable. This may be due in part to their being much more familiar with the handling and exercising after six weeks. However, pre-exercise heart rates were still elevated over the respective resting values in the eighth week. This type of anticipation to exercise has also been shown to increase the oxygen consumption (Shepherd and Gollnick, 1976) and rectal temperature (Gollnick and Ianuzzo, 1968) of rats. The resting heart rates (Table 3) obtained after the animals had rested for at least one-half hour are similar to those reported by other investigators (Tipton et al., 1966; Gollnick and Ianuzzo, 1968; Barnard et al., 1974). Basal heart rates (Table 3) were recorded during the light portion of the animal's daily cycle and only reported if the animal remained asleep. Basal heart rates decreased significantly from the second to eighth experimental week.

On a number of occasions, heart rates were recorded in the 700 to 900 beats/min. range (Appendix G). This tachycardia usually occurred when the animal became frightened with the heart rate

returning to normal within a few seconds. In man maximal exercise heart rates are the same as those elicited under heavy emotional stress. It may be that the maximal exercise heart rates reported here and elsewhere are not exceeded during exercise because cardiac output would not be augmented due to decreased filling. However, when using the rat in exercise and emotionally stressful environments, the heart rate may be elevated beyond the functional range and hence became less efficient. If this is the case, it certainly suggests that electric shock as a motivator may be counter productive for optimal cardiac function during exercise.

The heart rate response of the rat to various levels of power output (Fig. 10) is different than the heart rate response observed in man. Figure 10 illustrates the rapid response of the heart to various power outputs. Popovic et al. (1969) have reported that stroke volume does not increase with exercise in the rat. Therefore, it appears that any increase in cardiac output would come solely from an increase in heart rate. Hence, in order to elevate cardiac output heart rate is at or near maximal values at the low power outputs (Figure 10). Since oxygen consumption continues to rise at power output levels above the levels where heart rate has levelled off, the increased oxygen consumption must be achieved by enhanced extraction at the tissue level. Certainly the oxidative potential of rat skeletal muscle responds very quickly to aerobic conditioning programs (Holloszy et al., 1975).

Table 4 shows the data obtained on 3 animals running at varying speeds and inclinations on a traditional horizontal treadmill. When speed was held constant and grade increased or vice versa

an increase in oxygen consumption was observed. For example, at 26.8 m/min. BL3 increased his oxygen consumption from 53.2 ml/kg/min. at 4° grade to 68.7 ml/kg/min. at 10° grade to a further increase of 78.2 ml/kg/min. at 16° grade. This is in agreement with Wilson et al. (1978) and follows the same pattern that exists in man (Mathews and Fox, 1976). However, it is in disagreement with the work of Shepherd and Gollnick (1976) and does not support the findings of Taylor et al. (1972). Taylor et al (1972) have reported that in animals weighing less than 1 kg body weight, the metabolic cost of running is not significantly changed by the angle of the running surface. Shepherd and Gollnick (1976) support this finding with rats using a running wheel. Therefore, since both speed and grade on the horizontal contribute to the metabolic overload on the animal, comparisons between studies wherein different grades and speeds are used become tenuous. If standard elevations could be adapted it would certainly improve the generalizability of the results. The vertical treadmill used in this study offers a reasonable alternative and permits the calculation of physical work and power.

A closer approximation of the power output on the horizontal treadmill can be estimated from the oxygen consumption collected at a specific speed and grade. Assuming that a given power output on either the vertical or horizontal requires the same amount of oxygen consumption, then the individual regression lines found in Appendix E could be used to estimate power output on the horizontal treadmill, if oxygen consumption was known.

General Discussion

One of the most common changes that occurs with physical conditioning is a lower heart rate at submaximal power outputs (Astrand, 1977). A common practice of the majority of researchers conditioning rats is to progressively increase the speed of the treadmill and duration of the run during the first few weeks. The animals are then maintained at a selected speed and duration throughout the remainder of the experiment. It is presumed that during the first few weeks the rat undergoes a progressive overload. However, once the criterion speed is reached and no further increase takes place it is doubtful as to whether an optimal conditioning effect occurs. In an attempt to overcome this problem, the heart rates of rats conditioned in the present study were monitored. The heart rates were maintained in a range of 580 to 600 beats per minute by varying the speed. A progressive increase in the power output was observed throughout and was a function of increasing speed and/or increasing body weight (see Appendix H).

Another common practice when conditioning rats is to utilize a multi-animal treadmill and therefore condition five to ten rats at the same time. When heart rates are measured at a common speed and grade, they vary considerably as shown in Table 4. For example, the three rats measured at 26.8 m/min., 4° grade demonstrated heart rates of 529, 546 and 563 beats/min. This could lead to a large variation in the values of a number of dependent variables commonly investigated since the relative intensity at which each animal is being conditioned is different. However, at the faster speeds and/or greater inclines, the heart

rates are more similar (Table 4). Since conditioning rats by heart rates is very time consuming and not practical if a large number is required, it is suggested that a grade of at least 10^{o} and a speed of approximately 30 m/min. be employed.

In the past, many investigators utilized changes in heart rate, muscle glycogen, etc., in an attempt to evaluate the strenuousness of the exercise since the measurement of oxygen consumption was difficult. Shepherd and Gollnick (1976) have suggested that the results from their study can be extrapolated to any type of running device where rats run at controlled speeds. They have assumed that an increase in grade does not increase metabolic rate as was discussed earlier. If their data is applied to the rats in the present study that were measured on the horizontal treadmill, then a gross over-estimation of their oxygen consumption would result. Therefore, it is suggested that the use of running speed to evaluate the strenuousness of the exercise bout is improper.

In man, the linear relationship between heart rate and oxygen consumption at submaximal power outputs allows the use of heart rates to estimate the strenuousness of exercise (Astrand, 1977). This is possible in man because of the 200% increase in heart rate from resting to maximal exercise allowing a wide range. However in the rat, heart rate increases only 50%. Therefore at low power outputs the heart rate is at near maximal values, while oxygen consumption is still at submaximal levels. This suggests that it would be dubious to predict oxygen consumption in the rat from heart rate.

There are many similarities with regard to the rat and man

such as the linear relationship between oxygen consumption and power output, etc. However, there are a few dissimilarities such as the rapid increase to maximum heart rate which render the rat as less than an excellent experimental model for studying the systemic adaptation to exercise. However, it is suggested that for the study of peripheral adaptations, the rat remains a more than adequate model since the increase in oxygen consumption would come mainly from the extraction of oxygen at the tissue level and not because of an increase in cardiac output.

Conclusions

1. Body weight was lowest in the experimental group which was exposed to the greatest amount of total work. It appears that body weight changes are not only dependent upon the age and sex of the animal but also upon the duration, intensity and total work of the exercise and/or conditioning program.

2. The conditioning program failed to produce a significant difference in maximal oxygen consumption between the experimental groups in spite of substantially different amounts of chronic exercise. However, the slopes of the regression lines for the conditioned and non-conditioned groups were significantly different. This suggests that an adaptation in the conditioned group has occurred.

3. A linear relationship exists between oxygen consumption (l/min) and power output.

4. Heart rate approaches maximal values at low power output levels. However, oxygen consumption continues to rise at power out put levels where heart rate has levelled off. This suggests that the increased oxygen consumption must be achieved by enhanced extraction at the tissue level.

5. The different slopes in conjunction with similar oxygen consumption values for the different groups suggest that the rat may not be an ideal model for man when studying exercise adaptations in the oxygen transport system. However, it is suggested that for the study of peripheral adaptations, the rat remains a more than adequate model since the increase in oxygen consumption would come

from the extraction of oxygen at the tissue level and not because of an increase in cardiac output.

Recommendations

1. There is a need for further research to determine if a mathematical relationship exists between different mechanical and metabolic power outputs on the vertical and horizontal treadmills.

2. Future investigation might be aimed at determining the aerobic - anaerobic components of both conditioned and non-conditioned rats at varying power outputs.

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APPENDIX A

REVIEW OF RELEVANT LITERATURE

REVIEW OF RELEVANT LITERATURE

During the past ten years, researchers have shown a substantial number of physiological changes to occur in the rat with conditioning. The conditioning protocols that have been used are markedly different, thereby making comparisons between studies extremely difficult. In the present study, a vertical treadmill was utilized which allows the power output performed by the rat to be measured. Along with the measurement of metabolic work and the heart rate responses to various power outputs, the ability to Quantify the conditioning stimulus was enhanced.

MODES OF CONDITIONING

A variety of methods have been used by investigators in an attempt to study exercise-related phenomena in small animals. The most common methods used are running animals on a motor-driven treadmill, running wheel, exercise drum or exposing the animal to swimming with an additional weight attached to the tail or thorax.

Until recently, motor-driven treadmills were homemade (Koniski, 1960; Critz and Merrick, 1962; Andrews, 1965; Brannon et al., 1968). The grade and speed of the treadmill could be altered to increase the power output of the animal. Electrical stimulation was employed as a motivational device for teaching animals to run. Some control over the power outputs was provided. However, there are a number of problems associated with conditioning animals on a motor-driven treadmill. If the treadmill accomodates several animals at a time then the running speed must be adjusted to the

slowest animal (Wells and Heusner, 1971). The power output performed by each animal is difficult to assess when they are conditioned in groups (Hardin, 1965). All animals can not be induced to train on a motor-driven treadmill every day and some refuse to run thereby being dragged or rolled on the treadmill surface with the possibility of injury occuring (Thomas and Miller, 1958; Andrews, 1965; Hanson et al., 1969). Frequently, animals will be bruised and cut in the area of the lower limb (Reardon, 1975) or develop sore feet from the surface of the treadmill, thereby missing sessions or being eliminated from the study (Hardin, 1965).

Wells and Heusner (1971) developed a controlled running wheel for small animals in an attempt to eliminate many of the above problems that occur with motor-driven treadmills. Groups of animals can be conditioned simultaneously with each animal allowed to respond individually to their running program. The speed and duration of running can be regulated, therefore continuous or intermittent conditioning programs are possible. A major drawback with this type of conditioning mode is that the power output is difficult to measure, since the animals do not always run in the same position in the wheel (Hardin, 1965).

Jenness and Byrd (1974) have recently designed a "live-in" exercise drum unit capable of housing and conditioning forty animals simultaneously. Handling of animals is eliminated, however animals can not be conditioned individually. The reported speed range is from 7.32 - 43.89 meters per minute, thus high intensity anaerobic conditioning would not be possible. The authors also

reported sore paw problems while conditioning a group for five days at 7.32 meters/min. for fifteen minutes each day. Calculation of the power output each animal performed would also be difficult with this apparatus.

Swimming has been a popular form of exercise employed by many laboratories. The equipment necessary is relatively inexpensive and simple. The laboratory rat requires no training because of their natural swimming ability. However, a number of factors can influence the swimming times of animals.

A number of investigators have shown marked reductions in swimming times of rats forced to swim in water temperatures different from body temperature (Tan et al., 1954; Baker and Horvath, 1964a; Beaton and Feleki, 1967).

Baker and Horvath (1964b) have reported that the swimming style of all animals is not the same. Some animals never allow their nostrils to drop below the surface of the water, whereas other animals sank for several seconds and then rose to the surface and swam for several seconds. A few rats would sink to the bottom of the tank, remain in a vertical position and exhale through their nostrils for as long as 20 seconds. This procedure was followed by a rapid ascent to the surface where swimming would take place for several seconds and then the sinking process was repeated.

In an attempt to eliminate the various styles of swimming by standardizing the power output, several methods of weighing rats have been employed (Hardin, 1865; 1968; Dawson and Horvath,

1970). Another source of variability in swimming is the possibility of trapped air bubbles in the fur which increases the buoyancy of the animals (Dawson and Horvath, 1970). Yevick et al. (1969) have reported an increase in chronic murine pneumonia with swimming rats as compared to the sedentary controls. This would imply that longitudinal studies in which swimming is used may not be advisable. In addition to the above factors that can affect swimming performance, the quantification of power output while swimming is not possible.

OXYGEN CONSUMPTION STUDIES (RAT)

Relatively little is known about the oxygen consumption of the rat during maximal exercise. Shepherd and Gollnick (1976) adapted a running wheel to determine oxygen consumption at a number of different speeds (16-67 m/min.) during a four to five week period. Their results demonstrated that oxygen consumption increased linearly with work intensity (running speed) up to maximum. A maximum oxygen consumption of 95.1 ± 1.4 ml/kg/min. was found to occur at a running speed of 49.5 m/min. The authors suggest that their results can be extrapolated to any type of running device where rats run at controlled speeds.

Recently, Brooks and White (1977) reported submaximal values of oxygen consumption around 80 ml/kg/min. in rats exercising at 43.1 m/min. on a 11.3^{o} slope. According to Shepherd and Gollnick's (1976) data a speed of 43.1 m/min. produces an oxygen consumption of approximately 88 ml/kg/min. The 8 ml/kg/min. difference could possibily be due to a younger rat used in the Brooks and White study

or a difference in the training modes used. The mean weight of their rats was 222 grams, whereas the rats used in the Shepherd and Gollnick study had a mean weight of 373 grams.

Taylor et al. (1970) developed a regression equation to predict oxygen consumption from running speed. Prediction of an oxygen consumption from their equation yields lower values than the equation developed by Shepherd and Gollnick (1976).

Wilson et al. (1978) have recently reported maximal values of oxygen consumption for untrained male and female (Sprague-Dawley and Okamato-Aoki strains) rats. A graded treadmill test produced maximal oxygen consumptions of 91 ± 11 and 87 ± 11 ml/kg/min. for male and female rats respectively. Maximal oxygen consumption was elicited at a treadmill speed of 30.3 m/min. with a 15° inclination. The authors have shown an increase in oxygen consumption with a progressive grade and speed.

Oxygen consumption in the swimming rat has been studied by a number of investigators (Baker and Horvath, 1964b; Kratzing and Mark, 1967; McArdle, 1967; Dawson and Horvath, 1970). Maximum values have been reported to range from 55 to 80 ml/kg/min. Comparisons between the studies becomes difficult because of the various methodologies utilized by each laboratory.

McArdle (1967) suggests that the addition of weight does not increase the oxygen consumption in many animals, but actually reduces the ability of the animal to exchange gases at the surface. Therefore, swimming may lend itself to submaximal exercise programs but is less suited to programs of near maximal intensity (Hardin, 1965; McArdle, 1967).

EVALUATION OF WORK CAPACITY

Oscai and Molé (1975) suggest that the work capacity of animals can be evaluated by subjecting them to a run or swim to exhaustion and then compare the results of the conditioned versus the control animals. The animal may be considered exhausted when it can no longer right itself after being placed on its back (Oscai and Mole, 1975) or if the animal sits at the back of the treadmill for a period of more than 10 seconds, despite being subjected to electric shock (Jobin, 1977).

A graded treadmill test for rats has been developed by Wranne and Woodson (1973) for determination of maximal work performance. The speed and inclination are progressively increased from 26.8 m/min. at 12.5° grade to 34.8 m/min. at a 27° grade or until exhaustion occurs. A linear increase in heart rate with an increasing power output occurred from a average of 412 ± 20 beats/min. pre-exercise to an average of 615 ± 12 beats/min. at maximum. Arterial lactate also increased progressively from rest to maximum. The authors suggest that the test is suited to detect changes in blood oxygen transport.

OXYGEN CONSUMPTION STUDIES (MAN)

The determination of maximal oxygen consumption in man has received considerable attention in the literature. A variety of continuous (Balke, 1959; Cureton, 1969; Kamon and Pandolf, 1972b; Tolson and Ismail, 1970) and discontinuous (Taylor et al., 1955; Mitchell et al., 1958; Astrand et al., 1959; Macnab et al., 1969) tests have been developed to elicit maximal oxygen consumption

utilizing the treadmill, bicycle ergometer and laddermill.

It was determined by Taylor et al. (1955) that increasing the speed and keeping the grade constant was not as effective for obtaining an asymptote as increasing the grade with the speed held constant. Shepherd and Gollnick (1976) reported that the increase in grade was not as important as increasing the speed in rats which is contrary to what has been observed in man.

The precise power ouptut can be obtained on the bicycle ergometer and laddermill, whereas, the power output of uphill running is confounded by a horizontal component (Kamon and Pandolf, 1972b).

Kamon (1972a) reported a linear relationship between oxygen consumption and power output on both the laddermill and bicycle ergometer. Laddermill climbing was found to elicit maximal oxygen consumption values similar to uphill running but higher than cycling (Kamon and Pandolf, 1972b).

Because of the complexity of the direct measurement of oxygen consumption as well as the physical demand made upon the individual, a number of indirect methods of predicting maximal oxygen consumption have been developed. The indirect tests assume a linear relationship between heart rate and oxygen consumption and therefore extrapolation to a predicted maximum heart rate will yield a prediction of maximal oxygen consumption (Anderson et al., 1971). One of the most popular indirect tests was developed by Astrand and Ryhming (1954). A nomogram is used to compute maximal oxygen consumption from the heart rate after a submaximal

bicycle ergometer ride. When this test is compared to a maximum bicycle test predicted maximal oxygen consumption is higher (Glassford et al., 1965). The reason for this may be due to the fact that the submaximal test to predict maximal oxygen consumption is not as fatiguing on the leg muscles as the maximal test.

Hermiston and Faulkner (1971) used a stepwise multiple-regression technique to develop equations for the prediction of maximal oxygen consumption of physically active and inactive men. For example, the equation for active men takes into account the age of the subject, fat free weight, heart rate, fraction of carbon dioxide in expired gas, tidal volume at submaximal work level and respiratory exchange ratio. The correlation coefficient between the observed and predicted oxygen consumption was found to be 0.90. Other investigators (Mastopaolo, 1970; Metz and Alexander, 1971; Jessup et al., 1974) have improved upon the predictive validity of simple regression models by including a wide variety of respiratory and cardiovascular variables.

For the prediction of maximal oxygen consumption in man, a considerable body of knowledge has accumulated in the literature over the years. However, our knowledge of the physical work capacity of the rat is extremely limited. There has been a scarcity of material in the literature concerning the rat, therefore researchers have not been able to quantify their training programs. If we are to continue to use the rat to study the effects of exercise then the relative intensity of their conditioning programs must be known.

APPENDIX B

RAW DATA

Appendix B-1 Body weights for the different experimental groups $\bar{x} \pm S\ E\ (N)$

Time (days)	C1	C2	E1	E2	SC
1	98.7 ± 4.8(5)	98.6 ± 3.9(5)	89.9 ± 2.4(5)	91.3 ± 3.3(5)	97.9 ± 2.3(10)
5	102.4 ± 1.4(5)	112.2 ± 2.4(5)	101.0 ± 3.1(5)	104.4 ± 3.3(5)	114.4 ± 2.9(10)
8	120.3 ± 2.2(5)	127.7 ± 4.1(5)	116.6 ± 3.0(5)	129.0 ± 3.4(5)	133.2 ± 3.1(10)
10	128.6 ± 4.2(5)	135.1 ± 4.0(5)	129.1 ± 2.2(5)	139.5 ± 2.0(5)	146.0 ± 3.7(10)
12	136.1 ± 0.7(5)	145.6 ± 3.9(5)	141.3 ± 3.4(5)	150.7 ± 5.1(5)	158.9 ± 4.2(10)
15	155.5 ± 1.6(5)	166.8 ± 5.0(5)	161.6 ± 3.4(5)	170.6 ± 5.8(5)	176.2 ± 5.1(10)
18	180.1 ± 2.7(5)	187.4 ± 5.6(5)	180.1 ± 4.6(5)	189.1 ± 5.9(5)	194.5 ± 6.4(10)
20	189.8 ± 4.1(5)	198.6 ± 4.0(5)	194.9 ± 4.1(5)	202.9 ± 5.4(5)	207.9 ± 6.9(10)
22	199.1 ± 6.1(5)	209.7 ± 5.4(5)	206.3 ± 4.9(5)	216.1 ± 5.7(5)	224.5 ± 7.7(10)
24	212.8 ± 6.3(5)	220.7 ± 6.2(5)	219.4 ± 5.9(5)	226.6 ± 3.7(5)	235.6 ± 9.4(10)
27	222.5 ± 10.3(5)	241.7 ± 7.6(5)	241.3 ± 5.6(5)	246.5 ± 5.0(5)	258.7 ± 9.8(10)
30	230.4 ± 12.6(5)	249.5 ± 8.0(5)	256.3 ± 7.3(5)	260.8 ± 4.1(5)	272.1 ± 9.8(10)
32	238.1 ± 13.0(5)	260.5 ± 10.1(4)	258.4 ± 7.5(5)	273.5 ± 4.5(5)	285.3 ± 9.8(10)
34	249.8 ± 14.1(5)	273.0 ± 10.9(4)	261.8 ± 9.0(5)	287.3 ± 2.8(5)	296.8 ± 9.9(10)
35	254.8 ± 12.9(5)	275.1 ± 11.5(4)	267.5 ± 7.8(5)	284.1 ± 3.4(5)	295.8 ± 10.4(10)
38	262.5 ± 15.9(5)	282.2 ± 14.1(4)	290.4 ± 9.2(5)	304.6 ± 3.1(5)	318.5 ± 9.5(10)
41	259.9 ± 12.2(4)	286.7 ± 15.2(4)	287.2 ± 8.8(4)	316.3 ± 2.5(5)	326.1 ± 10.1(10)
45	271.5 ± 15.0(4)	306.7 ± 16.9(4)	304.1 ± 11.0(4)	341.1 ± 3.4(5)	349.3 ± 10.1(10)
48	282.1 ± 17.5(4)	303.4 ± 13.9(3)	319.6 ± 12.3(4)	358.7 ± 3.8(5)	362.0 ± 10.8(10)
52	284.9 ± 18.7(4)	318.0 ± 19.4(3)	326.1 ± 15.5(4)	376.0 ± 6.3(5)	380.0 ± 11.0(8)
58	307.8 ± 18.4(4)	330.5 ± 24.4(3)	347.2 ± 15.2(4)	386.0 ± 11.2(5)	384.7 ± 11.0(8)

Appendix B-2 Raw data for maximal oxygen consumption test on the vertical treadmill

Group	Animal Number	Weight (grams)	Power Output (watts)	Heart Rate (b/min)	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)
SC	GRR	370.7	Pre-exercise	445	0.0150	40.46
			0.519	558	0.0235	63.39
			0.821	593	0.0269	72.57
			0.958	600	0.0301	81.20
SC	GRP	396.9	Pre-exercise	420	0.0121	30.49
			0.556	563	0.0256	64.50
			0.691	579	0.0296	74.58
			0.804	600	0.0321	80.88
			0.947	610	0.0343	86.42
			1.108	600	0.0331	83.44
SC	RBK	347.9	Pre-exercise	400	0.0104	29.89
			0.487	558	0.0200	57.49
			0.606	585	0.0211	60.65
			0.771	600	0.0273	78.47
			0.899	600	0.0280	80.48
SC	RBL	360.4	Pre-exercise	-	0.0111	30.80
			0.505	-	0.0255	70.45
			0.628	-	0.0270	74.92
			0.730	-	0.0299	82.96
			0.860	-	0.0327	90.73
			0.931	-	0.0302	83.80

Appendix B-2 continued

Group	Animal Number	Weight (grams)	Power Output (watts)	Heart Rate (b/min)	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)
SC	GBK	397.2	Pre-exercise	-	0.0114	28.70
			0.557	-	0.0248	62.44
			0.692	-	0.0259	65.21
			0.745	-	0.0279	70.24
			0.805	-	0.0270	68.07
SC	RPL	347.2	Pre-exercise	-	0.0121	34.85
			0.411	-	0.0178	51.27
			0.549	-	0.0183	52.71
			0.769	-	0.0212	61.06
			0.897	-	0.0249	71.72
SC	GRB	358.6	Pre-exercise	-	0.0109	30.40
			0.424	-	0.0211	58.84
			0.567	-	0.0237	66.09
			0.727	-	0.0246	68.60
			0.794	-	0.0234	65.25
SC	BLB	426.5	Pre-exercise	390	0.0118	27.67
			0.505	585	0.0285	66.82
			0.674	600	0.0315	73.86
			0.864	610	0.0335	78.55
			0.945	610	0.0339	79.48
			1.018	600	0.0332	77.84

Appendix B-2 continued

Group	Animal Number	Weight (grams)	Power Output (watts)	Heart Rate (b/min)	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)
E1	BL1	377.8	Pre-exercise	364	0.0124	33.17
			0.441	585	0.0200	53.65
			0.559	581	0.0225	60.22
			0.589	590	0.0262	70.28
			0.699	600	0.0278	72.70
			0.755	600	0.0265	71.08
E1	BK1	307.2	Pre-exercise	393	0.0139	45.27
			0.364	578	0.0162	52.73
			0.486	580	0.0215	69.99
			0.576	600	0.0232	75.52
			0.681	581	0.0221	72.04
E1	GR1	331.5	Pre-exercise	375	0.0142	42.98
			0.392	571	0.0169	50.98
			0.459	578	0.0199	60.03
			0.524	580	0.0222	66.97
			0.621	571	0.0283	85.37
			0.734	571	0.0254	76.62
E1	PBK	337.9	Pre-exercise	368	0.0128	37.88
			0.473	541	0.0201	59.49
			0.589	565	0.0243	71.92
			0.685	571	0.0259	76.65
			0.749	571	0.0245	72.51

Appendix B-2 continued

Group	Animal Number	Weight (grams)	Power Output (watts)	Heart Rate (b/min)	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)
E1	GBB	339.8	Pre-exercise	416	0.0150	44.14
			0.476	545	0.0183	53.86
			0.592	554	0.0196	57.68
			0.637	577	0.0215	63.27
			0.688	580	0.0225	66.22
			0.753	600	0.0210	61.79
			0.811	590	0.0190	55.97
E2	PR4	363.2	Pre-exercise	436	0.0183	50.27
			0.430	600	0.0216	59.47
			0.574	600	0.0225	61.92
			0.681	610	0.0240	66.08
			0.736	600	0.0254	69.93
			0.805	590	0.0238	65.53
E2	BK4	368.4	Pre-exercise	420	0.0101	27.42
			0.516	566	0.0191	51.85
			0.642	581	0.0225	61.07
			0.746	600	0.0269	73.02
			0.816	600	0.0241	65.42
E2	GR4	400.1	Pre-exercise	393	0.0120	29.99
			0.474	581	0.0209	52.24
			0.633	600	0.0245	61.24
			0.750	610	0.0261	65.23
			0.811	600	0.0251	62.73

Appendix B-2 Continued

Group	Animal Number	Weight (grams)	Power Output (watts)	Heart Rate (b/min)	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)
E2	PRG	410.1	Pre-exercise	413	0.0098	23.90
			0.485	585	0.0185	45.11
			0.575	590	0.0224	54.62
			0.714	605	0.0264	64.38
			0.769	600	0.0253	61.69
C1	PR3	313.1	Pre-exercise	421	0.0148	47.21
			0.371	571	0.0152	48.55
			0.495	590	0.0197	62.92
			0.587	600	0.0234	74.74
			0.634	615	0.0260	83.04
			0.694	600	0.0241	76.81
C1	PRR	313.8	Pre-exercise	436	0.0099	31.62
			0.371	571	0.0169	53.86
			0.496	600	0.0206	65.65
			0.587	600	0.0264	84.13
			0.634	600	0.0241	76.80
C1	BK3	306.6	Pre-exercise	390	0.0110	35.82
			0.363	571	0.0186	60.67
			0.428	590	0.0204	66.54
			0.534	593	0.0254	82.84
			0.679	571	0.0216	70.46
			0.792	568	0.0214	69.80

Appendix B-2 Continued

Group	Animal Number	Weight (grams)	Power Output (watts)	Heart Rate (b/min)	$\dot{V}O_2$ (l/min)	$\dot{V}O_2$ (ml/kg/min)
C1	BL3	241.1	Pre-exercise	414	0.0094	38.60
			0.286	545	0.0137	56.59
			0.341	564	0.0151	62.37
			0.383	564	0.0172	71.05
			0.424	571	0.0184	76.00
			0.536	581	0.0211	87.15
			0.676	545	0.0195	80.55
C2	GR2	366.8	Pre-exercise	413	0.0140	37.99
			0.434	565	0.0258	70.34
			0.639	578	0.0276	75.25
			0.743	580	0.0307	83.70
			0.873	554	0.0281	76.81
C2	BL2	303.2	Pre-exercise	364	0.0098	32.32
			0.359	565	0.0162	53.43
			0.479	576	0.0191	63.02
			0.528	581	0.0218	71.92
			0.568	585	0.0252	83.14
			0.614	585	0.0248	81.79
C2	BK2	301.8	Pre-exercise	393	0.0102	33.80
			0.357	545	0.0198	65.61
			0.423	576	0.0214	70.91
			0.477	590	0.0223	73.89
			0.526	590	0.0252	83.50
			0.611	581	0.0243	80.52

Appendix B-3 Raw data for heart rates during the 2nd. week

Group	Basal	Resting in cage	Pre-exercise	Maximum Exercise
SC	-	-	462	655
	-	-	514	679
	-	-	545	643
	-	-	480	632
	379	405	467	658
	-	-	500	643
	-	-	500	632
	-	-	525	655
E1	384	412	494	655
	-	-	505	655
	424	486	525	624
	-	-	494	658
E2	408	500	525	667
	-	-	500	655
	-	-	494	632
	-	-	500	624
	-	-	-	667
C1	-	-	480	647
	405	384	480	658
	-	-	514	658
	-	-	545	643
C2	444	494	500	621
	-	-	494	667
	-	-	514	632
	-	-	545	624
	-	-	494	643

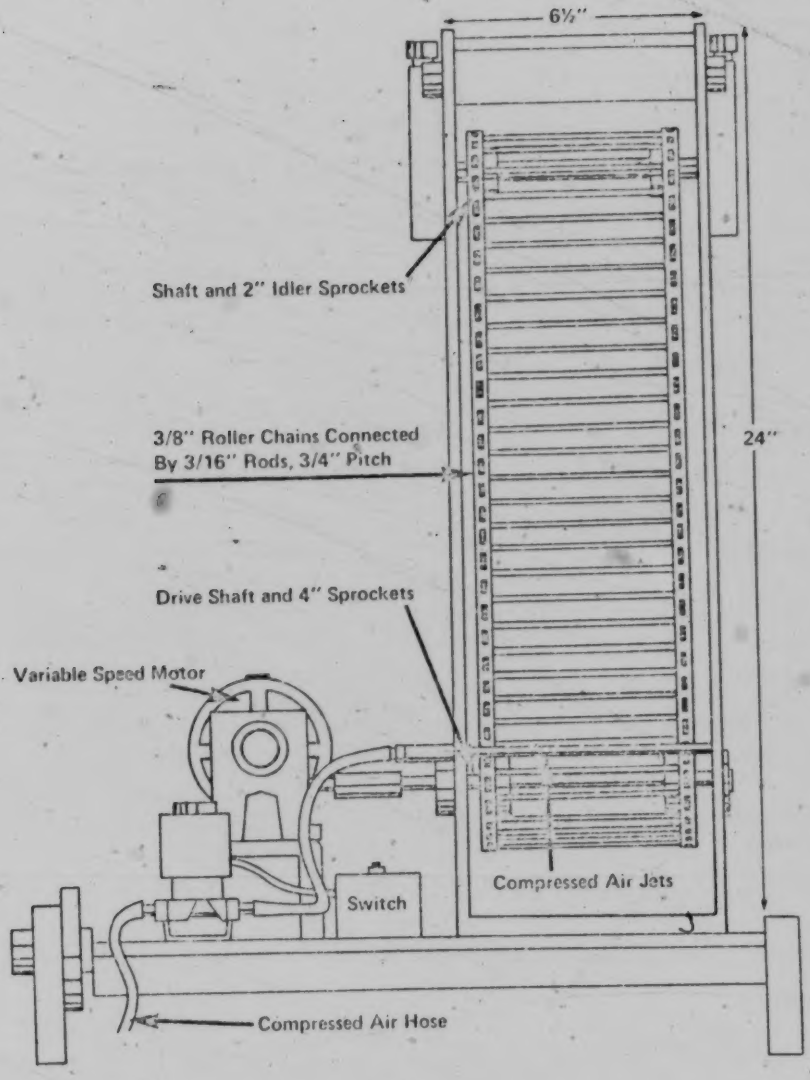
Appendix B-4 Raw data for heart rates during the 8th. week

Group	Basal	Resting in cage	Pre-exercise	Maximum Heart Rate
SC	-	-	445	600
	305	380	420	610
	-	-	400	600
	-	-	-	-
	-	-	-	-
	-	-	-	-
	-	-	-	-
	-	-	390	610
E1	269	335	364	600
	-	-	393	600
	-	-	375	580
	315	333	368	571
	-	-	416	600
E2	-	-	436	610
	-	-	420	600
	-	-	393	610
	-	-	413	605
C1	-	-	421	615
	-	-	436	600
	305	-	390	593
	307	369	414	581
C2	-	-	413	580
	-	-	364	585
	-	-	393	590

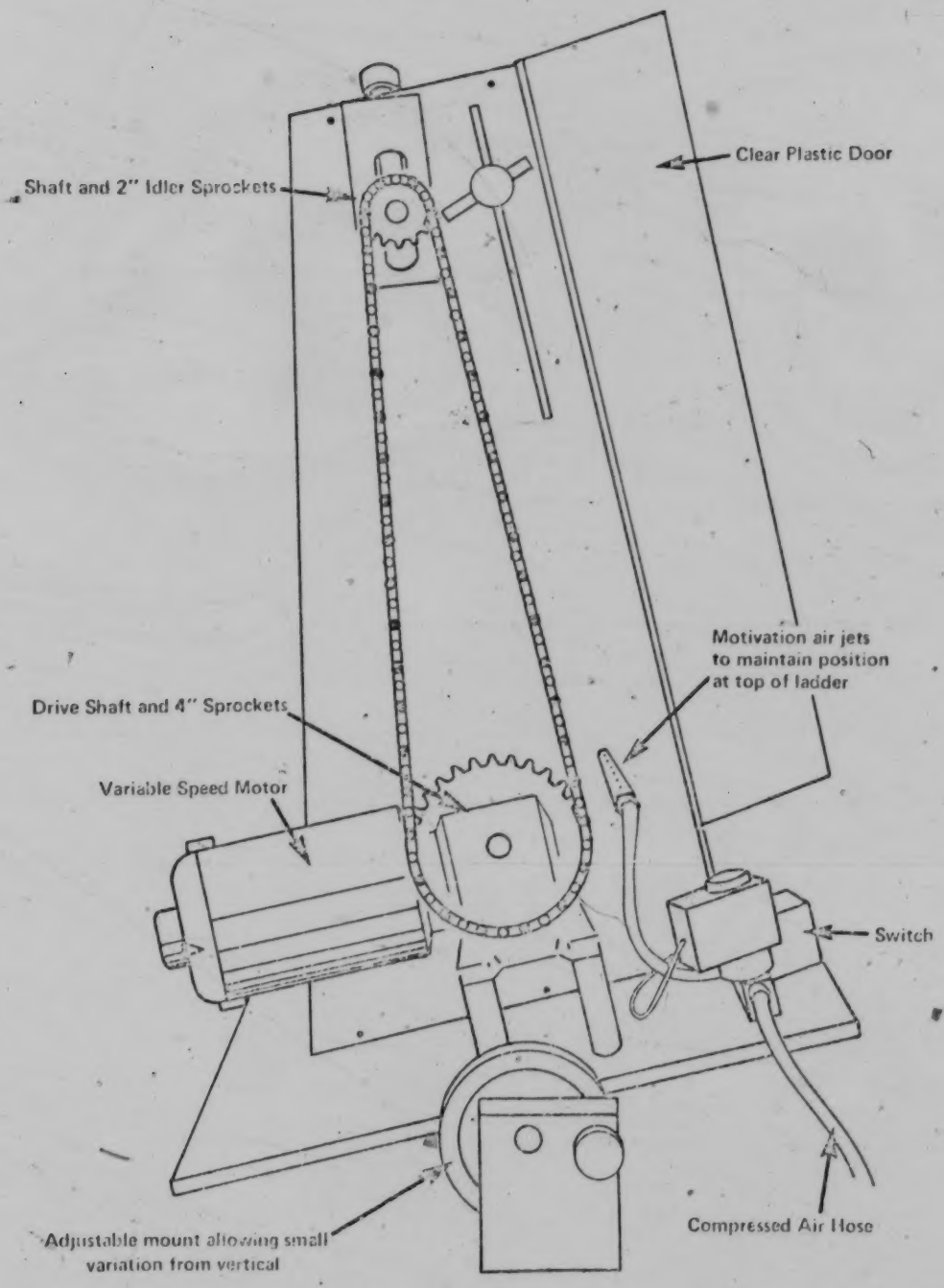
APPENDIX C

DESCRIPTION OF VERTICAL TREADMILL

RAT ERGOMETER



RAT ERGOMETER


Shaft and 2" Idler Sprockets
Clear Plastic Door
Motivation air jets to maintain position at top of ladder
Drive Shaft and 4" Sprockets
Variable Speed Motor
Switch
Adjustable mount allowing small variation from vertical
Compressed Air Hose

APPENDIX D

TRAINING PROGRSSION

Appendix D-1 Training progression for groups E1, E2 and SC

Day	Time	Speed (m/min)	Rep.	Total on (min:sec)	Total off (min:sec)
1	AM	5.2	1	00:30	-
2	AM	5.2	2	01:00	00:30
3	AM	5.2	3	01:30	00:30
5	AM	5.2	3	02:15	00:30
6	AM	5.2	3	03:00	00:30

From this point on, the animals in group SC were trained for a duration of 1 - 2 min. once a week, whereas animals in groups E1 and E2 were exercised at a heart rate range of 580 to 610 beats/min.

12	AM	1	03:00	-
	PM	1	03:00	-
16	AM	1	01:00	-
	PM	1	01:00	-
19	AM	1	04:00	-
	PM	1	04:00	-
23	AM	1	01:00	-
	PM	1	01:00	-
26	AM	1	05:00	-
	PM	1	05:00	-
30	AM	1	01:00	-
	PM	1	01:00	-
33	AM	1	06:00	-
	PM	1	06:00	-
37	AM	1	01:00	-
	PM	1	01:00	-
40	AM	1	07:00	-
	PM	1	07:00	-
44	AM	1	01:00	-
	PM	1	01:00	-
47	AM	1	08:00	-
	PM	1	08:00	-
51	AM	1	01:00	-
	PM	1	01:00	-

Appendix D-2 Training progression for groups C1 and C2

Day	Time	Speed (m/min)	Rep.	Total on (min:sec)	Total off (min:sec)
1	AM	5.2	1	00:30	-
2	AM	5.2	2	01:00	00:30
3	AM	5.2	3	01;00	00:30
5	AM	5.2	3	02:15	00:30
6	AM	5.2	3	03:00	00:30

From this point on, the animals in groups C1 and C2 were conditioned at a heart rate range of 590 to 610 beats/min.

8	AM	1	03:00	-
	PM	1	03:00	-
10	AM	1	04:00	-
	PM	1	04:00	-
11	AM	1	05:00	-
	PM	1	05:00	-
14	AM	1	06:00	-
	PM	1	06:00	-
15	AM	1	07:00	-
	PM	1	07:00	-
17	AM	1	08:00	-
	PM	1	08:00	-
18	AM	1	09:00	-
	PM	1	09:00	-
21	AM	1	10:00	-
	PM	1	10:00	-
22	AM	1	11:00	-
	PM	1	11:00	-
24	AM	1	12:00	-
	PM	1	12:00	-
25	AM	1	13:00	-
	PM	1	13:00	-
28	AM	1	14:00	-
	PM	1	14:00	-
29	AM	1	15:00	-
	PM	1	15:00	-
31	AM	1	15:00	-
	PM	1	15:00	-
32	AM	1	15:00	-
	PM	1	15:00	-
35	AM	1	15:00	-
	PM	1	15:00	-

Appendix D-2 continued

Day	Time	Speed (m/min)	Rep.	Total on (min:sec)	Total off (min:sec)
36	AM		1	15:00	-
	PM		1	15:00	-
38	AM		1	15:00	-
	PM		1	15:00	-
39	AM		1	15:00	-
	PM		1	15:00	-
42	AM		1	15:00	-
	PM		1	15:00	-
43	AM		1	15:00	-
	PM		1	15:00	-
45	AM		1	15:00	-
	PM		1	15:00	-
46	AM		1	15:00	-
	PM		1	15:00	-
49	AM		1	15:00	-
	PM		1	15:00	-
50	AM		1	15:00	-
	PM		1	15:00	-

APPENDIX E

INDIVIDUAL REGRESSION LINES

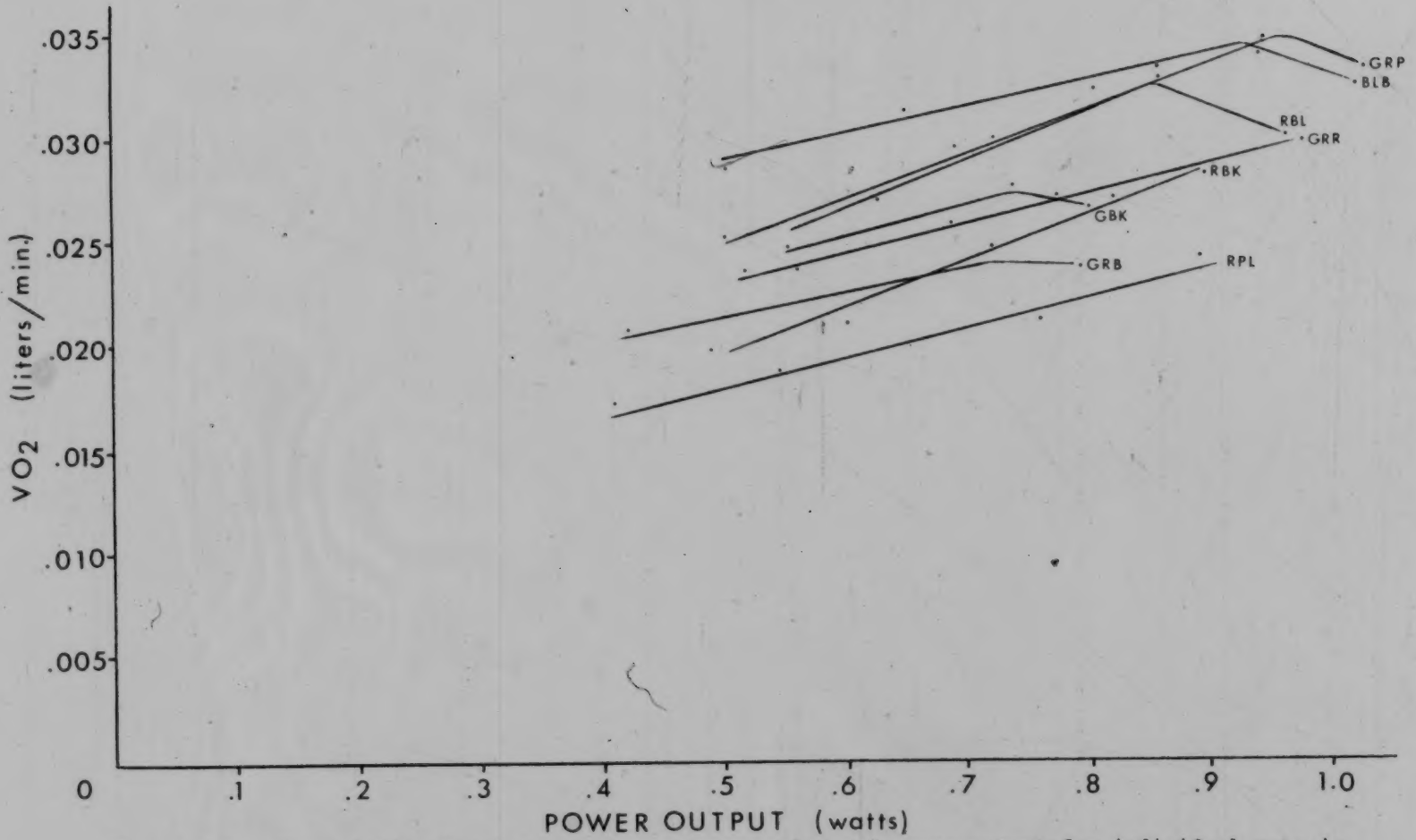


Figure E-1 The relationship between oxygen consumption and power output for individual rats in the sedentary control group (SC)

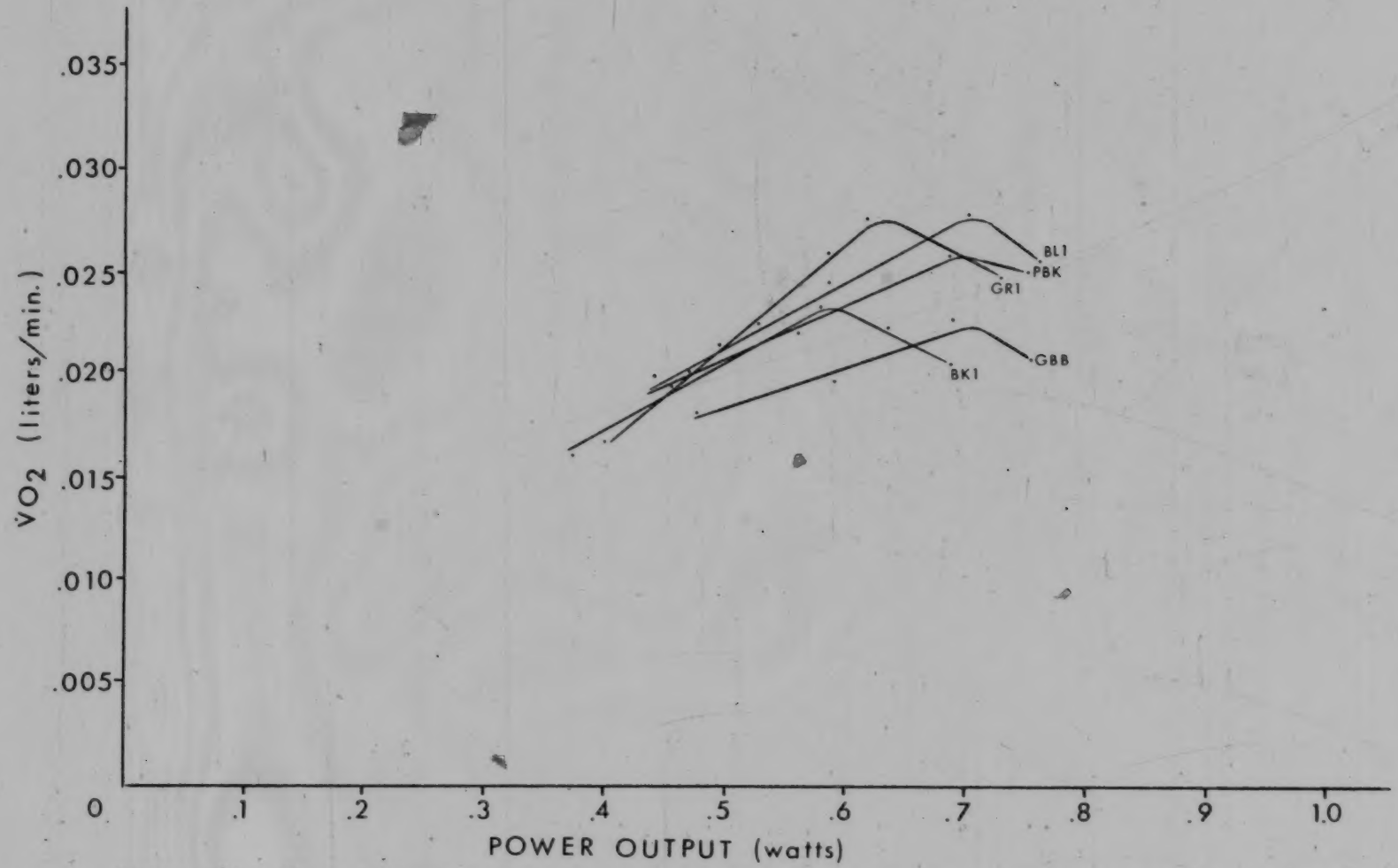


Figure E-2 The relationship between oxygen consumption and power output for individual rats in the exercise-run wheel group (E1)

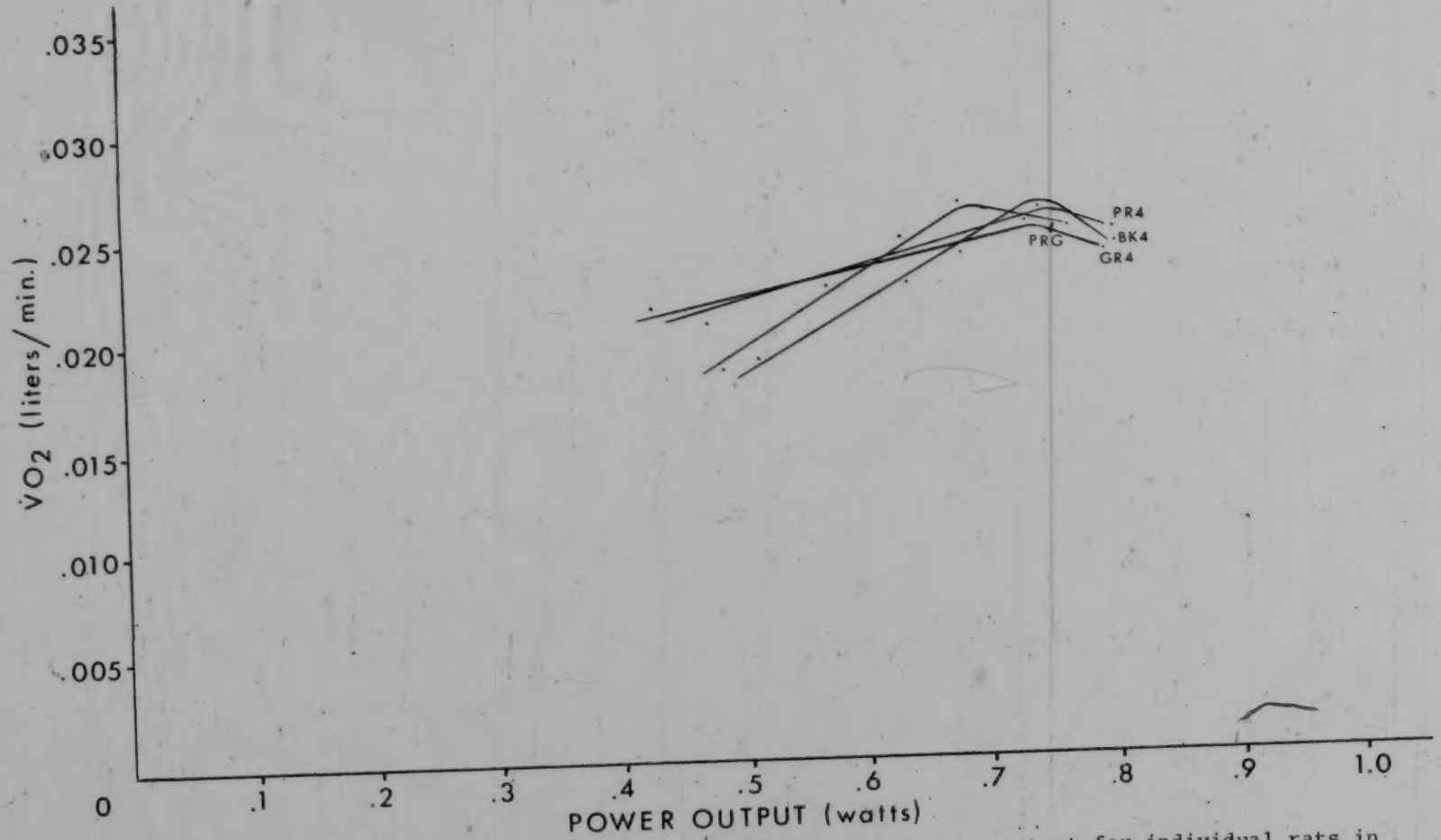


Figure E-3 The relationship between oxygen consumption and power output for individual rats in the exercised group (E2)

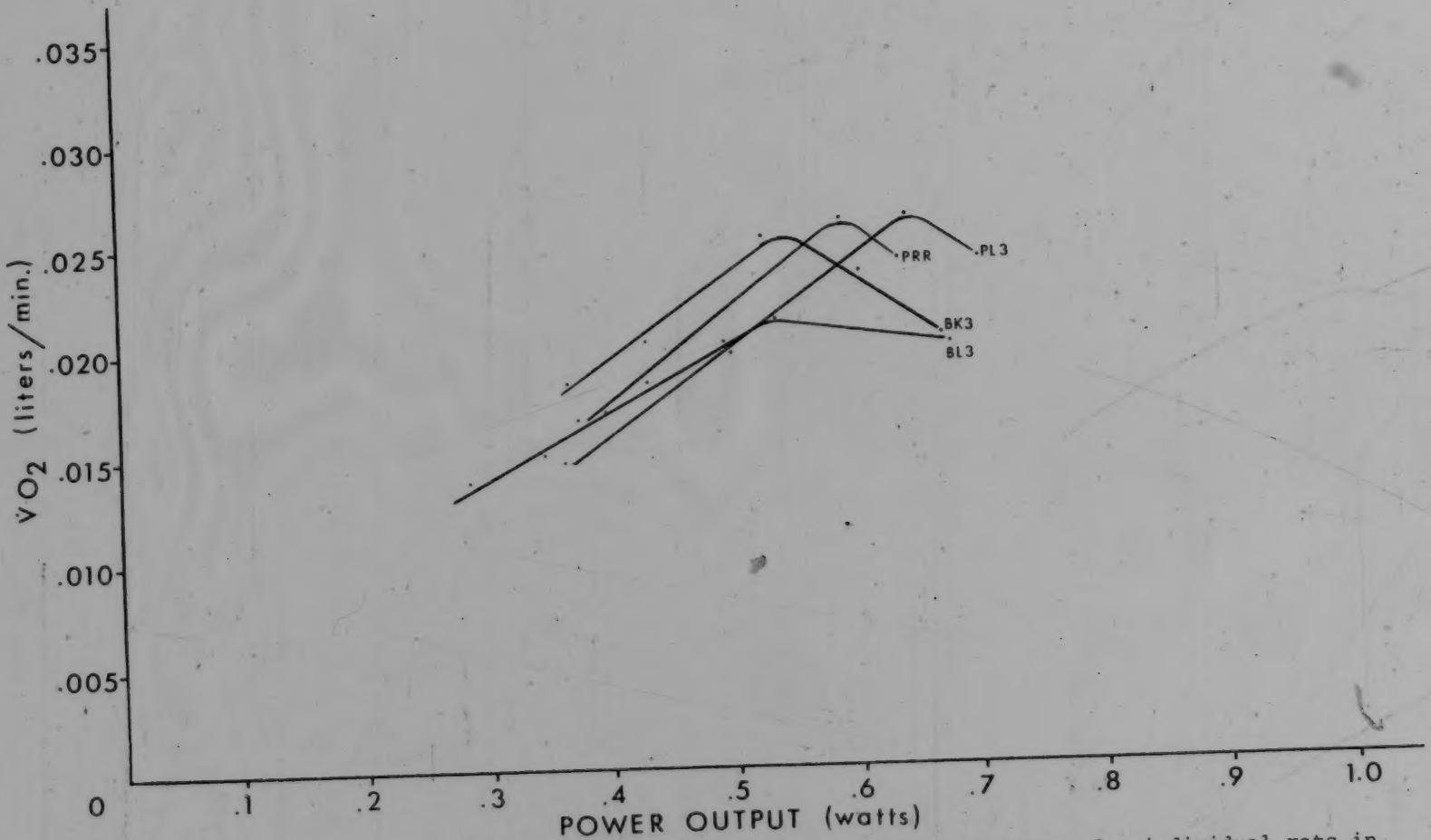


Figure E-4 The relationship between oxygen consumption and power output for individual rats in the conditioned-run wheel group (C1)

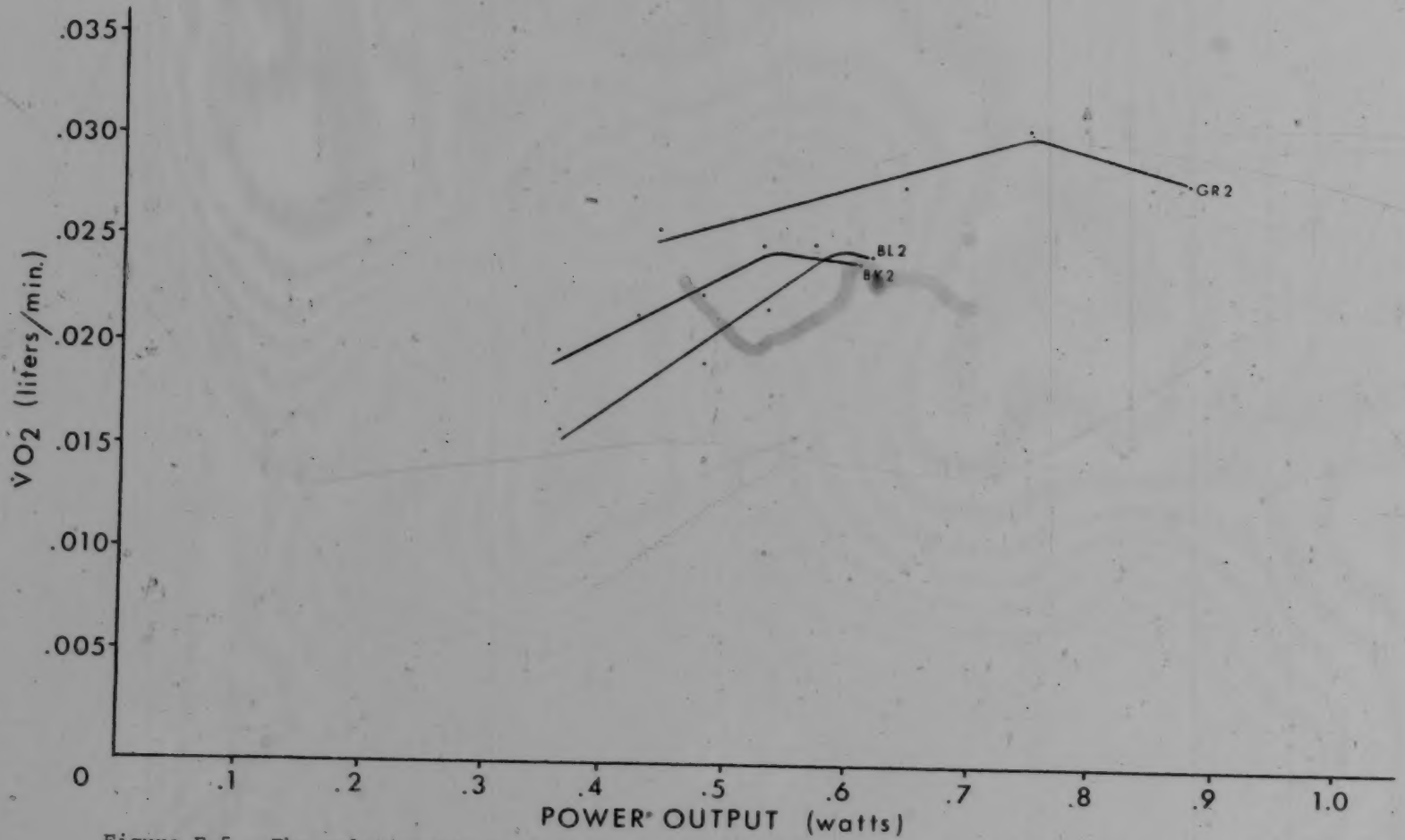


Figure E-5 The relationship between oxygen consumption and power output for individual rats in the conditioned groups (C2)

APPENDIX F

SUMMARY OF STATISTICAL TESTS

Appendix F-1, a Summary of the analysis of variance for body weights of sedentary control, exercised and conditioned rats at the time of arrival in the laboratory

Source of Variation	DF	SS	MS	F	P
Groups	4	401.63	100.41	1.61	>0.05
Error	25	1555.62	62.21		

$F_{0.05}$ (4, 25) 2.76

Appendix F-1, b Summary of the analysis of variance for body weights of sedentary control, exercised and conditioned rats at the termination of the study

Source of Variation	DF	SS	MS	F	P
Group	4	23134.4	5783.5	5.81	<0.01
Error	19	18907.1	995.1		

$F_{0.01}$ (4, 19) 4.50

Appendix F-1, c Newman-Keuls comparison between ordered means for body weight of sedentary control, exercised and conditioned rats at the end of the study

	C1	C2	E1	SC	E2
Means	307.8	330.5	347.2	384.7	386.0
307.8	0.0	22.7**	39.4**	76.9**	78.2**
330.5		0.0	16.7*	54.2**	55.5**
347.2			0.0	37.5**	38.3**
384.7				0.0	1.3
386.0					0.0
R=		2	3	4	5

The Multiplier is 3.7969

** $p < 0.01$

* $p < 0.05$

Appendix F-2, a Summary of the analysis of variance for maximal oxygen consumption (ml/kg/min) of sedentary control, exercised and conditioned rats

Source of Variation	DF	SS	MS	F	P
Groups	4	673.94	168.49	4.63	<0.01
Error	19	690.72	36.35		

$F_{0.01}$ (4, 19) 4.50

Appendix F-2, b Newman-Keuls comparison between ordered means for maximal oxygen consumption (ml/kg/min.) of sedentary control, exercised and conditioned rats

	E2	E1	SC	C1	C2
Means	68.14	75.29	78.61	83.45	84.29
68.14	0.00	7.15	10.47*	15.31**	16.15**
75.29		0.00	3.32	8.16	9.00
78.61			0.00	4.84	5.68
83.45				0.00	0.84
84.29					0.00
R=		2	3	4	5

The Multiplier is 2.9021

** p <0.01

* P <0.05

Appendix F-3 Summary of the Analysis of variance for pre-exercise oxygen consumptions of sedentary control, exercised and conditioned rats

Source of Variation	DF	SS	MS	F	P
Groups	4	311.76	77.94	1.87	>0.05
Error	19	790.41	41.60		

$F_{0.05}$ (4, 19) 2.90

Appendix F-4 Summary of the analysis of variance for maximum heart rate of sedentary control, exercised and conditioned rats during the 8th experimental week

Source of Variation	DF	SS	MS	F	P
Groups	4	1261.70	315.43	2.99	>0.05
Error	15	1584.30	105.62		

$F_{0.05}$ (4, 15) 3.06

Appendix F-5 Summary of the analysis of varianse for pre-exercise heart rate of sedentary control, exercised and conditioned rats during the 8th experimental week

Source of Variation	DF	SS	MS	F	P
Groups	4	4153.90	1038.48	2.27	>0.05
Error	15	6877.30	458.49		

$F_{0.05}$ (4, 15) 3.06

Appendix F-6 Summary of the analysis of variance for maximum heart rate of sedentary control, exercised and conditioned rats during the 2nd experimental week

Source of Variation	DF	SS	MS	F	P
Groups	4	619.97	154.99	0.58	>0.05
Error	21	5634.07	268.29		

$F_{0.05}$ (4, 21) 2.84

Appendix F-7 Summary of the analysis of variance for pre-exercise Heart rate of sedentary control, exercised and conditioned rats during the 2nd experimental week

Source of Variation	DF	SS	MS	F	P
Groups	4	340.79	85.20	0.14	>0.05
Error	21	11766.58	560.31		

$F_{0.05}$ (4, 20) 2.87

Appendix F-8 Summary of the test for homogenity of regression of conditioned (C1 and C2 pooled) and unconditioned (E1, E2 and SC pooled) groups

Source of Variation	DF	SS	MS	F	P
Groups	1	0.0000494	0.0000494	5.55	<0.05
Error	83	0.0000730	0.0000009		

$F_{0.05}$ (1, 80) 3.96

Appendix F-9 Summary of analysis of variance for maximal oxygen consumption (l/min) of sedentary control, exercised and conditioned rats

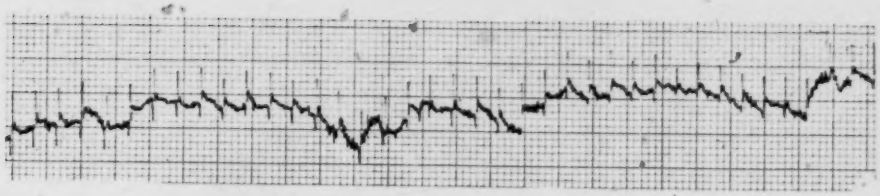
Source of Variation	DF	SS	MS	F	P
Groups	4	0.00009	0.00002	2.26	>0.05
Error	19	0.00017	0.000009		

$F_{0.05}$ (4,19) 2.90

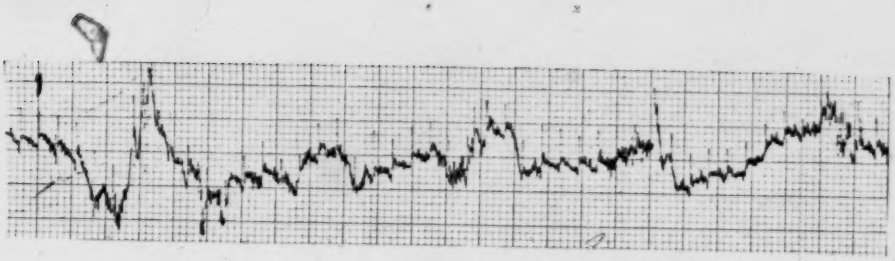
APPENDIX G

ECG TRACINGS

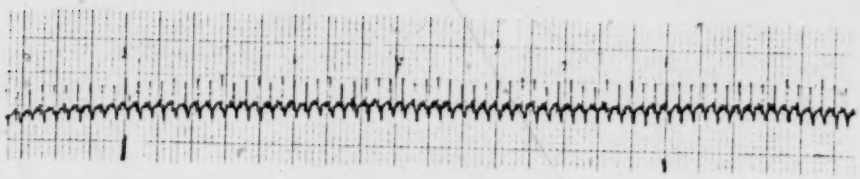
Appendix G An example of the ECG tracing for pre-exercise, submaximal exercise and paroxysmal tachycardia the rat (paper speed at 25 mm/sec).



Pre-exercise - 450 beats/min.



Submaximal exercise - 578 beats/min.



Paroxysmal tachycardia - 846 beats/min.

APPENDIX H

EXAMPLE OF PROGRESSIVE INCREASE
IN POWER OUTPUT AT 580-600 B/M.

Appendix H Example of the increase in power output maintaining heart rate in the 580-600 b/min. range for BL3

Experimental Day	Speed (m/sec)	Weight (grams)	Power Output (watts)
15	0.125	157	0.186 *
16	0.125	174	0.206
19	0.133	180	0.227 *
20	0.133	179	0.225
22	0.148	197	0.276
23	0.157	187	0.278 *
26	0.157	217	0.323
27	0.157	200	0.297 *
29	0.167	202	0.319 *
30	0.167	217	0.343
33	0.167	200	0.316 *
34	0.175	219	0.363
36	0.184	226	0.394
37	0.192	218	0.396 *
40	0.204	229	0.442
41	0.204	223	0.431 *
43	0.214	226	0.468 *
44	0.223	231	0.488

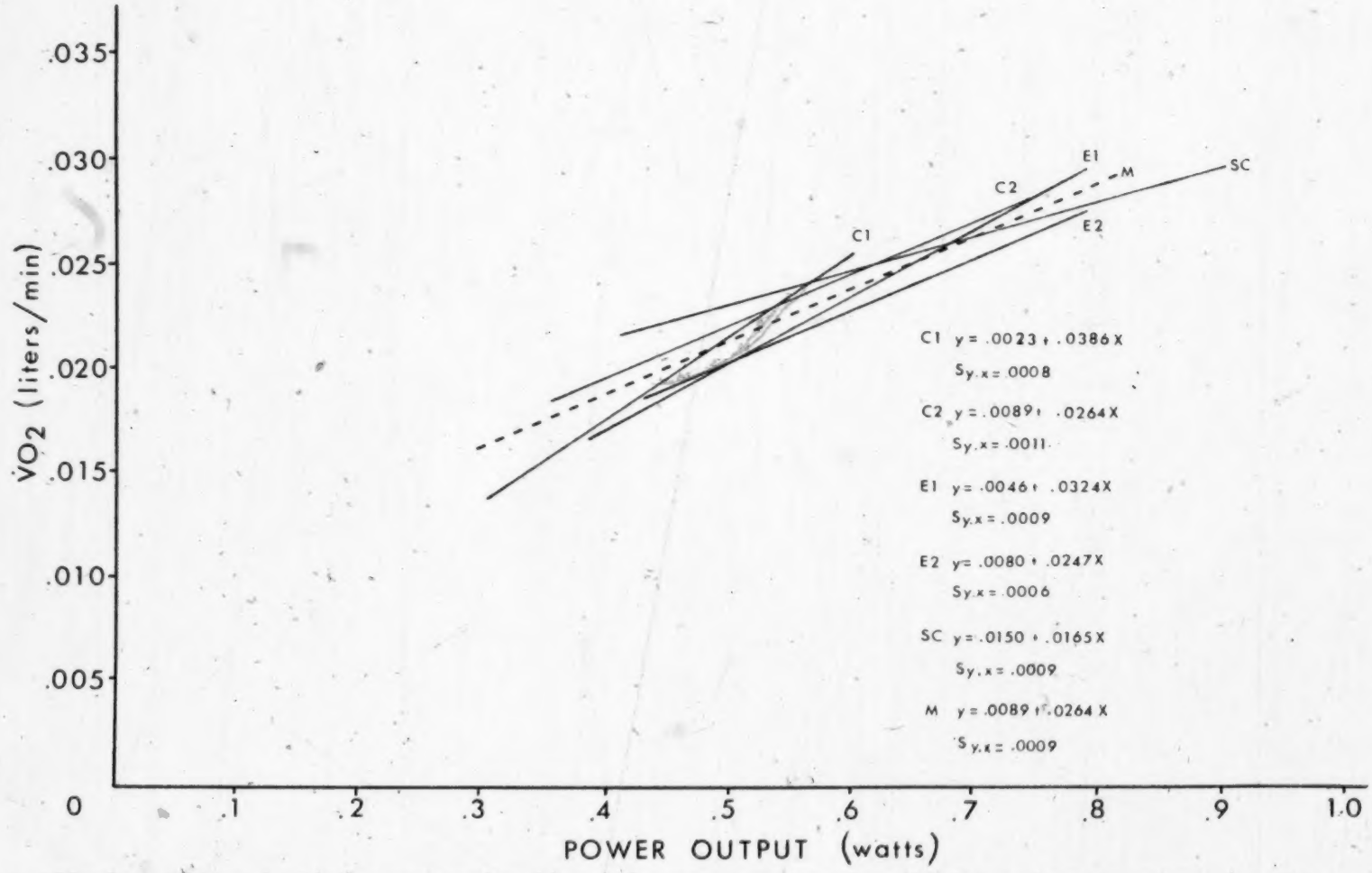
* housed in run wheel for that day.

ADDENDUM

Addendum

During the review of this thesis, it was suggested that the group regression lines for each experimental group be calculated in a different manner. Since the slopes of the individual regression lines (Appendix E) in each group are very similar, they were averaged and the group regression line formed. This method seperated the groups (Addendum Fig. 1) to a greater extent than the original procedure (Fig. 9). The standard error of estimate for each group was also reduced.

The conditioned-run wheel (C1) group was significantly different from all other groups. The conditioned (C2) and exercised-run wheel (E1) groups showed no significant difference. This suggests that the voluntary run wheels imposed a stress that produced a similar conditioning protocol used in the present study. This method also reinforces the possibility that at the higher power outputs, the conditioned rats are able to meet the increased demands through increased aerobic metabolism, whereas, the non-conditioned animals derived a greater percentage of the required energy to perform the work from anaerobic sources.



Addendum Figure 1 Linear regression lines of oxygen consumption (l/min) and power output for the conditioned-run wheel(C1), conditioned (C2), exercised-run wheel (E1), exercised (E2), sedentary control (SC) and overall regression (M) line

Addendum Summary of the test for homogenity of regression of sedentary control, exercised and conditioned groups

Source of Variation	DF	SS	MS	F	P
Groups	4	0.0006544	0.0001636	2.70	<0.05
Error	81	0.0007415	0.0000092		

$F_{0.05}$ (4, 80) 2.48

Newman-Keuls comparison between ordered means for regression slopes of sedentary conrol, exercised and conditioned rats

	SC	E2	C2	E1	C1
Means	0.0165	0.0247	0.0285	0.0324	0.0386
0.0165	0.00	0.0082**	0.0120**	0.0159**	0.0221**
0.0247		0.00	0.0038	0.0077**	0.0139**
0.0285			0.00	0.0039	0.0101**
0.0324				0.00	0.0062*
0.0386					0.00
R =		2	3	4	5

The Multiplier is 0.0014599

** $p<0.01$

* $p<0.05$